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STATE GEOLOGICAL SURVEY

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BULLETIN No. 7.

Physical Geography of the Evanston-Waukegan Region

BY

Wallace W. Atwood and James Walter Goldthwait

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STATE GEOLOGICAL COMMISSION.

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R. D. SALISBURY, *Consulting Geologist,* in charge of the preparation of Educational Bulletins.

[redacted]

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STATE GEOLOGICAL SURVEY, UNIVERSITY OF ILLINOIS.
URBANA, ILL., OCT. 25, 1907.

Governor C. S. Deneen, Chairman and Members of the Geological Commission:

GENTLEMEN—I submit herewith a report upon the physical geography of the Evanston-Waukegan region, with the recommendation that it be published as Bulletin 7 of the survey. This report has been prepared under the direction of Professor R. D. Salisbury of the University of Chicago, consulting geologist of this survey. It forms the first of a series now in preparation of "Educational Bulletins." These have been called educational because their purpose is to put useful information concerning the geology and geography of the State, or some parts of it, before those who are not special students of these sciences. More particularly, their purpose is to put into available form such knowledge as will help those who are not geologists in understanding the common phenomena of their own regions. The bulletins are therefore intended to serve the citizens at large, rather than special students of geology, or special industries of the State which depend, directly or indirectly upon the mineral resources. Other and more technical publications serve this latter purpose.

Two classes of people are kept especially in mind in the preparation of these bulletins. These are: (1) Intelligent citizens whose attention, for one reason or another, has never been directed to geology. Among such citizens there are always some who are interested in understanding their home regions; and through the understanding of one region the general principles of geology may be grasped, much more easily. The knowledge thus acquired may be a source of much satisfaction to those who possess it. Furthermore, there is always the possibility that occasion may arise in the future when the information can be turned to account in economic ways. (2) Teachers of physical geography and geology. These sciences are now taught somewhat generally in high schools, and might be pursued with great advantage much more widely than now in the country schools. According to the improved methods of study at the present time, it is essential that the subjects studied be so illustrated and applied that the kuowledge acquired becomes a part of the student's permanent equipment. His study of physical geography fails of its full purpose unless it puts him into possession of the ability to interpret

the surface of the land as he travels to and fro in after life. The best way to acquire this ability appears to be to make application of principles studied in the school to the phenomena of the region in which the school is located. Many of the principles of physical geography and geology are illustrated within easy reach of most of the schools in the State.

The second purpose of those bulletins, therefore, is to put the schools of the various parts of the State into possession of a general account of the principal geographic and geological features of their regions, which may be used as a sort of field book. This field study in physical geography serves the same purpose as laboratory work in physics and chemistry, in connection with those subjects.

It will be long before all the important regions of the State can be covered in this way. In the choice of areas selected for early treatment, three considerations have controlled. These are the following: (1). Areas of great inherent interest have taken precedence over those not so favored. (2). Areas of which topographic maps have been made take precedence over those not so mapped; and (3) areas where the bulletins are likely to be used, again have precedence. Topographic maps have as yet been made over but a relatively small portion of the State. Fortunately the lake shore from Chicago northward has now been mapped, the Waukegan quadrangle, immediately north of the Highwood and extending to the State line having just been completed.

This area, one of exceptional and varied interest from the point of view of physical geography, was chosen as the first to be reported on. Dr. Wallace W. Atwood of the University of Chicago, and Dr. James Walter Goldthwait of Northwestern University, already thoroughly familiar with the region, collaborated in the preparation of the accompanying report. It is hoped that the material here brought together will stimulate the interest not only of the citizens and students of the area, but that it may also enrich the teaching of physical geography throughout the State. The clear description of the action of the continental ice sheet which once covered the region, the fascinating history of Lake Michigan, and finally the analyses of the development of stream courses in the area should be of general interest. Incidentally the discussion of the water resources of the area is of practical importance to all residents of this thickly populated area.

The survey is under great obligations to Professor Salisbury and the authors of this report for its preparation. Acknowledgments should also be made to the U. S. Geological Survey for the use of figures 3 and 13, and to Director E. A. Birge of the Wisconsin Geological and Natural History Survey for the use of figures 11 and 12; fig. A, plate I: fig. B, plate VIII and fig. A and B, plate IX.

Others similar educational bulletins are being prepared and will be offered for publication as rapidly as circumstances will permit.

Respectfully,

H. Foster Bain,

Director.

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PHYSICAL GEOGRAPHY OF THE EVANSTON-WAUKEGAN REGION.

BY WALLACE W. ATWOOD AND JAMES WALTER GOLDTHWAIT.

GENERAL GEOGRAPHIC FEATURES.

(BY W. W. ATWOOD.)

Location and Extent of Area—The area with which this report is concerned lies north of Chicago, and extends northward to the Illinois-Wisconsin line. Its eastern boundary is the shore line of Lake Michigan, and its western margin, the DesPlaines river (Fig. 1). It is a little over 30 miles long and varies in width from 5 to 10 miles. Its area is about 250 square miles. Of this area, the portion immediately adjoining Lake Michigan has attracted most attention. It is a beautiful suburban-home district and a region of considerable scientific and educational interest. Each year hundreds, if not thousands of students visit points of special interest along this shore. It is not uncommon for special trains to be chartered and entire schools to be taken on educational excursions to this "North Shore" region. The portion near the lake may be regarded as a great physiographic laboratory.

The "Chicago region" is interpreted as the area mapped in the Chicago folio of the United States Geological Survey, and includes the area covered by the Calumet, Des Plaines, Riverside and Chicago sheets, of the U. S. Geological Survey. The north boundary of the Riverside and Chicago quadrangles,* latitude 42 degrees, is the southern boundary of the area here under discussion. The Evanston and Highwood quadrangles are located just north of the Chicago region and included within the region here concerned (Fig. 1).

The quadrangle adjoining the Highwood on the north, includes the Waukegan region and is known as the Waukegan quadrangle. This map will soon be ready for distribution.

* A quadrangle is the area represented on one sheet of the U. S. Geological Survey topographic map. Topographic maps of the quadrangles included in the Chicago folio and of the Evanston, Waukegan and Highwood regions may be purchased of the director of the U. S. Geological Survey, Washington, D. C., at 5 cents per copy or $3.00 per hundred. The Evanston, Waukegan and Highland sheets should be used in connection with this report, and the Chicago folio, also to be had of the U. S. Geological Survey, will also be instructive.

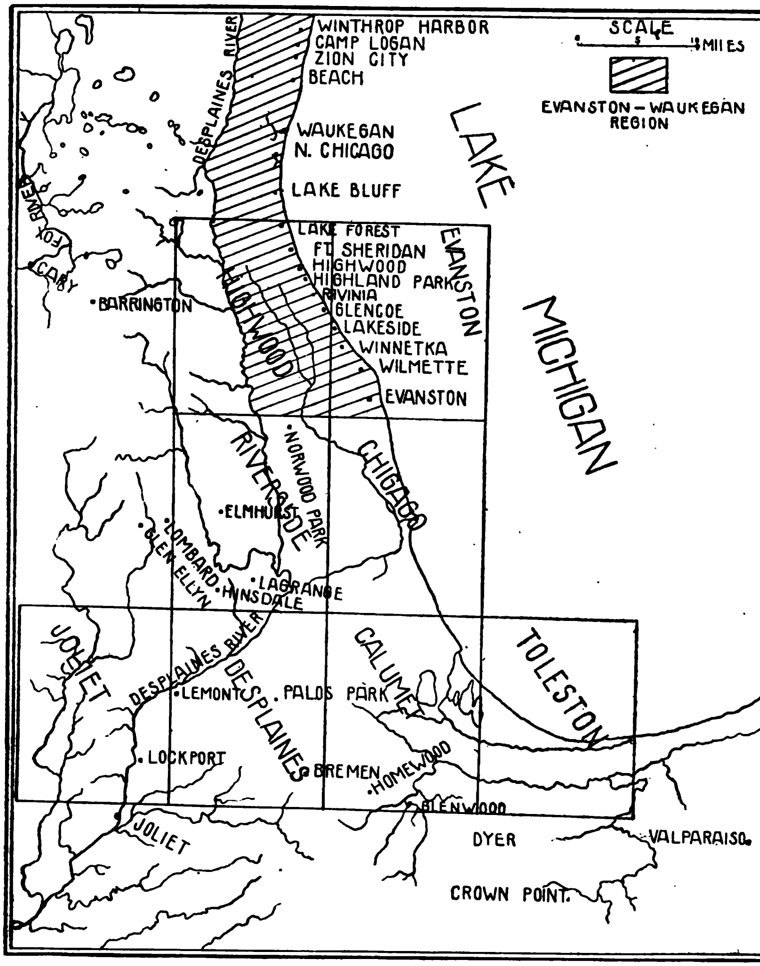

FIG. 1. General map showing location and extent of the Evanston-Waukegan region, the quadrangles for which topographic maps are available, and the chief points mentioned in the report.

The general geographic features of the region are: (1) the moraine plain or rolling upland, (2) the present shore, (3) the lake plain with associated beach ridges, and (4) the ravines.

Upland Area—The larger part of the area consists of rolling upland more than 60 feet above the level of the lake. Going northward from Chicago the Northwestern railroad bed becomes noticeably higher a few rods south of the station at Winnetka, and before the station is reached the road bed has passed from the lower, flatter plain to the south, to the rolling upland farther north. Northward from Winnetka the railroad remains on the upland to Waukegan, where it descends again to the lake plain. West of the railroad, the undulating

surface of the upland contains many swamps, ponds and other depressions without outlets. The topography is such as is common to glacial drift and it will be fully discussed later in the report.

Shore Line—The modern lake cliff extends from the southern margin of Waukegan southward a little beyond Evanston. It varies in height up to 80 feet, and at places is almost vertical. At the base of the cliff, is the modern beach. Over the beach zone, the waves and undertow work the sands and gravels back and forth. When strong winds blow from the east or northeast, the waves reach, at certain places, to the base of the cliff and thus submerge the entire beach. As the winds die down or set in from the west, the lake waters fall or are blown eastward, uncovering a wide beach. Normally there is a belt 50 to 100 feet wide bordering the water, and rising a few feet above the level of the lake.

Lake Plain—This appears in the southeast and northeast corners of the area. Evanston, Wilmette, Kenilworth and a portion of Winnetka are located on the plain at the southeast. The lower or manufacturing portion of Waukegan, most of Zion City, and all of Beach, Camp Logan and Winthrop Harbor are on the lake plain at the northeast corner of the area. The beaches associated with the plain are low, even-crested ridges of sand and gravel built upon the plain and running approximately parallel to the present shore line of the lake. At the landward margin of the lake plain there is usually a distinct rise of 10 to 60 feet to the upland. This is well shown at Winnetka and at Waukegan. In the southern portion of the area, in the vicinity of the Chicago river, the change from the plain to the upland is not abrupt, and the margin of the plain is not easily recognized.

East of the Northwestern railroad the upland belt has been dissected by numerous intermittent or wet-weather streams. The gullies and ravines which have resulted from the work of such streams add much to the roughness of the topography, and much to the scenic attractiveness of the region.

Drainage—The drainage of the western portion of the area joins the Des Plaines river, and thence by way of the Illinois and Mississippi enters the Gulf of Mexico. The central portion is drained by the north branch of the Chicago river. The waters following this route are now diverted up the south branch of the Chicago river into the Chicago drainage canal, and thence into the Des Plaines. The eastern border of the area is drained by numerous short streams into Lake Michigan. From the lake these waters may go in part southward through the Chicago outlet, and in part northward to the Atlantic ocean by way of the great lakes and the St. Lawrence river.

THE GEOLOGICAL FORMATIONS.

(BY W. W. ATWOOD.)

Nature of Materials—General Characteristics—All of the rock material within the Evanston-Waukegan region is ***glacial drift,*** composed of clay, sand, gravel and bowlders. A part of this material has been re-worked by rivers, winds, or waves since the ice retreated. Such material is stratified, and is sometimes called ***modified drift,*** and will receive special attention later. The portion that may be considered as ***unmodified,*** or but slightly modified glacial drift, underlies the lake plain and the entire upland. It is well exposed in the lake cliff, in many of the ravines, and in most all excavations. Road cuttings, sewer or water-pipe excavations, and all deep basements or cellars, when being excavated, afford excellent opportunities for studying this formation. The material grades from fine silt, to huge bowlders 10 or 12 feet in diameter. Between these extremes there are various grades of sand, gravel and cobble-stones. The great mass of the material is firmer than sand, and may be classed as *clay,* or better as *stony clay.*

In addition to the variation in size, there is variation in the kinds of rocks found in the drift. Almost any exposure in the region will yield four or five varieties, while on the beach it is easy to find 20 or more different kinds of stones.

The shapes of the pebbles and bowlders in the unstratified drift are not like those of stream or shore pebbles. Instead of having smoothly rounded forms, the stones of the drift are commonly sub-angular, with numerous flat faces, or facets. The facets usually show polishing, parallel grooving, and scratching, as though smoothed and striated while being held firmly in one position, and moved over a hard surface (Plate I, Fig. A).

Bed-rock Surface Beneath the Drift—Nowhere within the Evanston-Waukegan region, so far as the authors are aware, does the bed-rock underlying the glacial drift appear at the surface. The nearest exposures of the rock that underlies this area are within the Chicago region. When these exposures are examined they are usually found to be smoothed and polished, and marked by grooves and scratches similar to those upon the pebbles and bowlders in the drift. The scratches on the bed-rock are usually parallel at any one locality, but when examined at widely separated localities within the Chicago region, they are found to vary in direction from 20 degrees to 45 degrees south of west.

Structure—Any good section of the glacial drift along the north shore shows that most of the material is unstratified. In other words, the sand, clay, gravel and bowlders are at most places intimately intermingled, and show no signs of assortment. At a few places, most noticeably in the lake cliff just south of Pettibone creek, at North Chicago, the glacial material is assorted. Here sands and gravels of a given size are arranged in distinct lavers. Such material was evidently deposited by water, and presumably by water associated with the melting of the glacial ice which once covered the region.

The unassorted or unstratified glacial drift was deposited by the ice itself, and it now lies as the ice left it. As the ice melted or for any reason gave up the rock material it was carrying, such material was left on the surface beneath. In this process, there was no possibility of getting the sands or pebbles of a common size together. The material, large or small, which was left at one time, took its place on that which had been last deposited in the same place. Unstratified glacial drift is known as *till.*

The various phenomena of the drift of the region give unmistakable evidence of that agent that brought that material. The physical and structural features of the material are identical with those of the material carried or but recently deposited by the glaciers of today. The markings of the bed-rock surface, exposed in neighboring regions to the north and south, and underlying the same great sheet or drift that occupied the Evanston-Waukegan region, are identical with the markings of the bed-rock surfaces under living glaciers, and of rock surfaces from which glaciers have but recently retreated. Furthermore, the shapes and markings of the stones in the drift are identical with the shapes and markings of stones underneath and in the base of the glaciers of today. The drift is, therefore, of glacial origin.

Sources of the Drift Materials—The clay matrix of the drift is highly calcareous, and was derived largely from limestone and calcareous shale by grinding and crushing. The limestone was presumably the underlying Niagara formation which appears at several places in Chicago, and is reached in the deep wells of the Evanston-Waukegan region. This formation extends far to the northeast. Of the stones of the drift in this region, about 90 per cent are from the Niagara limestone, while the remaining 10 per cent are of sandstone, shales and crystalline rock, foreign to Illinois. From the direction of glacial striæ on bed-rock in Chicago and in southern Wisconsin, it is known that the glacier that brought the drift material to this region, moved southward in the basin of Lake Michigan and spread southward over the area bordering the lake on the west. If the course of the ice be retraced, it is found that the sandstones and crystalline rocks in the drift of this region must have come at least 500 miles, and may have traveled much farther. Such rocks occur, in place, about the eastern part of Lake Superior, northern Lake Huron, and further northward. The glacier that reached this area was therefore not local. Furthermore, drift similar to that in the Evanston-Waukegan region covers most of Illinois, and extends over

most of the northern United States and Canada. The drift of this region is therefore a part of a great sheet of drift deposited by a glacier of continental dimensious.

ORIGIN AND WORK OF CONTINENTAL GLACIERS.*

THE FORMATION OF AN ICE SHEET.

To clearly understand the origin of the drift, and the methods by which it attained its present widespread distribution, it is necessary to consider some elementary facts and principles concerning the formation and work of a continental glacier, even at the risk of repeating what is already familiar.

The temperature and the snow fall of a region may stand in such a relation to each other that the summers' heat may barely suffice to melt the winters' snow. If under these circumstances the annual temperature were to be reduced, or the fall of snow increased, the summer's heat would fail to melt all the winter's snow, and some portion of it would endure through the summer, and through successive summers, constituting a perennial snow field. Were this process once inaugurated, the depth of the snow would increase from year to year. The area of the snow field would be extended at the same time, since the snow field would so far reduce the surrounding temperature as to increase the proportion of the annual precipitation which fell as snow. In the course of time, and under favorable conditions, the area of the snow field would attain great dimensions, and the depth of the snow would become very great.

As in the case of existing snow fields, the lower part of the snow would eventually be converted into ice. Several factors would conspire to this end. 1. The pressure of the overlying snow would tend to compress the lower portion, and snow rendered sufficiently compact by compression would be regarded as ice. 2. Water arising from the melting of the surface snow by the summer's heat would percolate through the superficial layers of snow, and, freezing below, take the form of ice. 3. On standing, even without pressure or partial melting, snow appears to undergo changes of crystallization which render it more compact. In these and perhaps other ways, a snow field becomes an ice field, the snow being restricted to its surface.

Eventually the increase in the depth of the snow and ice in a snow field will give rise to new phenomena. Let a snow and ice field be assumed in which the depth of snow and ice is greatest at the center, with diminution toward its edges. The field of snow, if resting on a level base, would have some such cross-section as that represented in the diagram, Fig. 2.

* In the preparation of the text bearing on the principles of glaciation, free use has been made of material in Bull. V. Wisconsin Geological and Natural History Survey, Salisbury and Atwood.

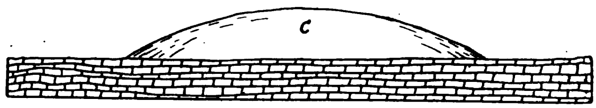

FIG. 2. Diagrammatic cross-section of a field of ice and snow (c) resting on a level base (a—b)

When the thickness of the ice has become considerable, it is evident that the pressure upon its lower and marginal parts will be great. We are wont to think of ice as a brittle solid. If in its place there were some plastic substances which would yield to pressure, the weight of the ice would cause the maginal parts to extend themselves in all directions by a sort of flowing motion.

Under great pressure, many substances which otherwise appear to be solid, exhibit the characteristics of plastic bodies. Among the substances exhibiting this property, ice is perhaps best known. Brittle and resistent as it seems, it may yet be molded into almost any desirable form is subjected to sufficient pressure, steadily applied through long intervals of time. The changes of form thus produced in ice are brought about without visible fracture. Concerning the exact nature of the movement, physicists are not agreed, but the result appears to be essentially such as would be brought about if the ice were capable of flowing, with extreme slowness, under great pressure continuously applied.

In the assumed ice field, there are the conditions for great pressure and for its continuous application. If the ice be capable of moving as a plastic body, the weight of the ice would induce gradual movement outward from the center of the field, so that the area surrounding the region where the snow accumulated would gradually be encroached upon by the spreading of the ice. Observation shows that this is what takes place in every snow field of sufficient depth. Motion thus brought about is glacier motion, and ice thus moving is glacier ice.

Once in motion, two factors would determine the limit to which the ice would extend itself: (1) the rate at which it advances; (2) the rate at which the advancing edge is wasted. The rate of advance would depend upon several conditions, one of which in all cases, would be the pressure of the ice which started and which perpetuates the motion. If the pressure be increased the ice will advance more rapidly, and if it advances more rapidly, it will advance farther before it is melted. Other things remaining constant, therefore, increase of pressure will cause the ice sheet to extend itself farther from the center of motion. Increase of snowfall will increase the pressure of the snow and ice field by increasing its mass. If, therefore, the precipitation over a given snow field be increased for a period of years, the ice sheet's marginal motion will be accelerated, and its area enlarged. A decrease of precipitation, taken in connection with unchanged wastage would decrease the pressure of the ice and retard its movement. If, while the rate of advance diminished, the rate of wastage remained constant, the edge of the ice would recede and the snow and ice field be contracted.

The rate at which the edge of the advancing ice is wasted depends largely on the climate. If, while the rate of advance remains constant, the climate become warmer, melting will be more rapid, and the ratio between melting and advance will be increased. The edge of the ice will therefore recede. The same result will follow if, while temperature remains constant, the atmosphere becomes drier, since this will increase wastage by evaporation. Were the climate to become warmer and drier at the same time, the rate of recession of the ice would be greater than if but one of these changes occurred.

If, on the other hand, the temperature over and about the ice-field be lowered, melting will be diminished, and if the rate of movement be constant, the edge of the ice will advance farther than under the earlier conditions of temperature, since it has more time to advance before it is melted. An increase in the humidity of the atmosphere, while the temperature remains constant, will produce the same result, since increased humidity of the atmosphere diminishes evaporation. A decrease of temperature, decreasing the melting, and an increase of humidity, decreasing the evaporation, would cause the ice to advance farther than either change alone, since both changes decrease the wastage. If, at the same time that conditions so change as to increase the rate of movement of the ice, climatic conditions so change as to reduce the rate of waste, the advance of the ice before it is melted will be greater than where only one set of conditions is altered. If, instead of favoring advance, the two series of conditions conspire to cause the ice to recede, the recession will likewise be greater than when but one set of conditions is favorable thereto.

Greenland affords an example of the conditions here described. The large part of the half million or more square miles which this body of land is estimated to contain, is covered by a vast sheet of snow and ice, thousands of feet in thickness. In this field of snow and ice, there is continuous though slow movement. The ice creeps slowly toward the borders of the island, advancing until it reaches a position where the climate is such as to waste (melt and evaporate) it as it advances.

The edge of the ice does not remain fixed in position. There is reason to believe that it alternately advances and retreats as the ratio between movement and waste increases or decreases. These oscillations in position are doubtless connected with climatic changes. When the ice edge retreats, it may be because the waste is increased, or because the snowfall is decreased, or both. In any case, when the ice edge recedes from the coast, it tends to recede until its edge reaches a position where the melting is less rapid than in its former position, and where the advance is counterbalanced by the waste. This represents a condition of equilibrium so far as the edge of the ice is concerned, and here the edge of the ice would remain so long as the conditions were unchanged.

When for a period of years the rate of melting of the ice is diminished, or the snowfall increased, or both, the ice edge advances to a new line where melting is more rapid than at its former edge. The edge of the ice would tend to reach a position where waste and advance balance. Here its advance would cease, and here its edge would remain so long as climatic conditions were unchanged.

If the conditions determining melting and movement be continually changing, the ice edge will not find a position of equilibrium, but will advance when the conditions are favorable for advance, and retreat when the conditions are reversed.

Not only the edge of the ice in Greenland, but the ends of existing mountain glaciers as well, are subject to fluctuation, and are delicate indices of variations in the climate of the regions where they occur.

The North American Ice Sheet—In the area north of the eastern part of the United States and in another west of Hudson Bay it is believed that ice sheets similar to that which now covers Greenland began to accumulate at the beginning of the glacial period. From these areas as centers, the ice spread in all directions, partly as the result of accumulation, and partly as the result of movement induced by the weight of the ice itself.

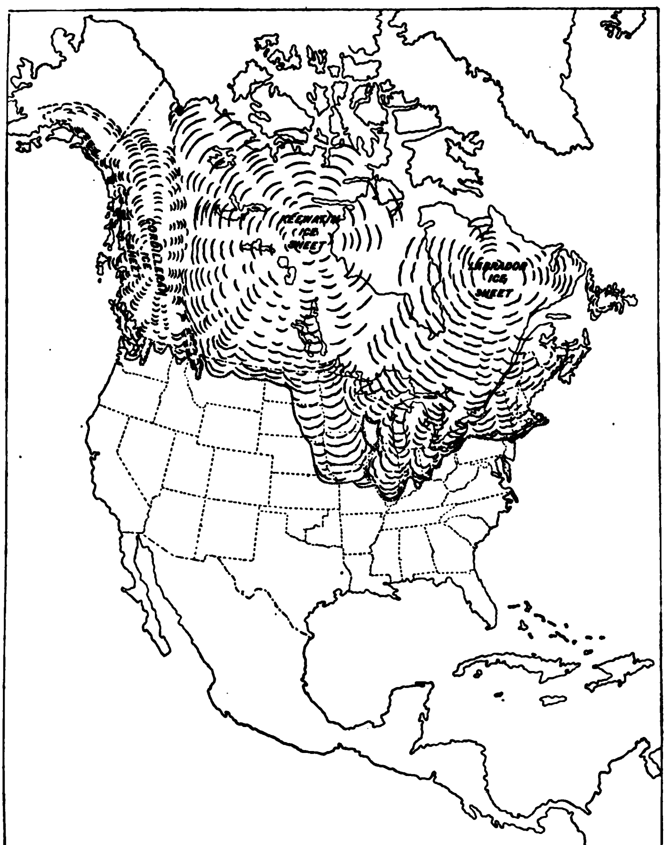

FIG. 3. Map of area covered by the North American ice sheet of the glacial epoch at its maximum extension, showing the approximate southern limit of glaciation, the three main centers of ice accumulation, and the driftless area within the border of the glaciated region. (*Courtesy of U. S. Geological Survey.*)

The ice sheets spreading from these centers came together south of Hudson's bay, and invaded the territory of the United States as a single sheet, which, at the time of its greatest development, covered a large part of our country (Fig. 3), its area being known by the extent of the drift which it left behind when it was melted. In the east, it buried the whole of New England, most of New York, and the northern part of New Jersey and Pennsylvania. Farther west, the southern margin of the ice crossed the Ohio river in the vicinity of Cincinnati, and pushed out over the uplands a few miles south of the river. In Indiana, except at the extreme east, its margin fell considerably short of the Ohio; in Illinois it reached well toward that river, attaining here its most southerly latitude. West of the Mississippi, the line which marks the limit of its advance curves to the northward, and follows, in a general way, the course of the Missouri river. The total area of the North America ice sheet, at the time of its maximum development, has been estimated to have been about 4,000,000 square miles, or about ten times the estimated area of the present ice-field of Greenland.

Within the general area covered by the ice, there is an area of several thousand square miles, mainly in south-western Wisconsin, where there is no drift. The ice, for some reason, failed to cover this *driftless area* though it overwhelmed the territory on all sides.

The Evanston-Waukegan region was affected by the ice of more than one glacial epoch, but the chief results now observable were effected during the last, and the others need not be considered. Figure 30 shows the maximum portion of ice in this region during the last glacial epoch.

WORK OF GLACIER ICE.

As the edge of an ice sheet, or as the end of a glacier, retreats, the land which it has previously covered is laid bare, and the effects which the passage of the ice produced may be seen. In some cases one may actually go back a short distance beneath the ice now in motion, and see its mode of work and the results it is effecting. The beds of living glaciers, and the beds which glaciers have recently abandoned are found to present identical features. Because of their greater accessibility, the latter offer the better facilities for determining the effects of glaciation.

The conspicuous phenomena of abandoned glacier beds fall into two classes, (1) those which pertain to the bed rock over which the ice moved, and (2) those which pertain to the drift left by the ice.

Erosive Work of the Ice—Effect on Topography—The leading features of the rock bed over which glacier ice has moved, are easily recognized. Its surface is generally smoothed and polished, and frequently marked by lines (striae) or groves, parallel to one another. An examination of the bottom of an active glacier discloses the method by which the polishing and scoring are accomplished.

The lower surface of the ice is thickly set with a quantity of clay, sand, and stony material of various grades of coarseness. These earthy and stony materials in the base of the ice are the tools with which it

works. Thus armed, the glacier ice moved slowly forward, resting down upon the surfaces over which it passes with the whole weight of its mass, and the grinding action between the stony layer at the base of the ice and the rock bed over which it moves, is effective. If the material in the bottom of the ice be fine, like clay, the rock bed is polished. If coarser materials, harder than the bed-rock, be mingled with the fine, the rock bed of the glacier will be scratched as well as polished. If there are bowlders in the bottom of the ice they may cut grooves or gorges in the underlying rock. The grooves may subsequently be polished by the passage over and through them of ice carrying clay or other fine, earthy matter.

All these phases of rock wear may be seen about the termini of receding glaciers, on territory which they have but recently abandoned. There can thus be no possible doubt as to the origin of the polishing, planing and scoring.

There are other peculiarities, less easily defined, which characterize the surface of glacier beds. The wear effected is not confined to the mere marking of the surface over which it passes. If prominences of rock exist in its path, as is often the case, they oppose the movement of the ice, and receive a corresponding measure of abrasion from it. If they be sufficiently resistant they may force the ice to yield by passing over or around them, but if they be weak, they are likely to be destroyed.

As the ice of the North American ice sheet advanced, seemingly more rigid when it encountered yielding bodies, and more yielding when it encountered resistant ones, it denuded the surface of its loose and movable materials, and carried them forward. This accumulation of earthy and stony debris in the bottom of the ice, gave it a rough and grinding lower surface, which enabled it to abrade the land over which it passed much more effectively than ice alone could have done. Every hill and every mound which the ice encountered contested its advance. Every sufficiently resistant elevation compelled the ice to pass around or over it; but even in these cases the ice left its marks upon the surface to which it yielded. The powerful pressure of pure ice, which is relatively soft, upon firm hills of rock, which are relatively hard, would effect little. The hills would wear the ice, but the effect of the ice on the hills would be slight. But where the ice is supplied with earthy and stony material derived from the rock itself, the case is different. Under these conditions, the ice, yielding only under great pressure and as little as may be, rubs its rock-shod base over every opposing surface, and with greatest severity where it meets with greatest resistance. Its action may be compared to that of a huge "flexible-rasp" fitting down snugly over hills and valleys alike, and working under enormous pressure.

The abrasion effected by a moving body of ice under such conditions would be great. Every inch of ice advance would be likely to be attended by loss to the surface of any obstacle over or around which it is compelled to move. The sharp summits of the hills, and all the angular rugosities of their surfaces would be filed off, and the hills smoothed down to such forms as will offer progressively less and less

resistance. If the process of abrasion be continued long enough, the forms, even of the large hills, may be greatly altered, and their dimensions greatly reduced. (Figs. 4 and 5.) Among the results of ice wear, therefore, will be a lowering of the hills, and a smoothing and softening of their contours, while their surfaces will bear the marks of the tools which fashioned them, and will be polished, striated or grooved, according to the nature of the material which the ice pressed down upon them during its passage.

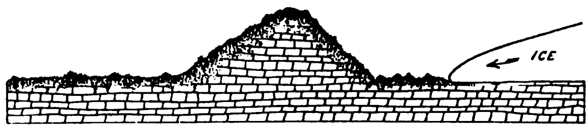

FIG. 4. A hill before the ice passes over it.

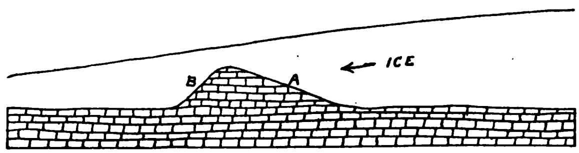

FIG. 5. The same hill after it has been eroded by the ice. *A*, the stoss side; *B*, the lee side.

It was not the hills alone which the moving ice affected. Where it encountered valleys in its course, they likewise suffered modification. Where the course of a valley was parallel to the direction of the ice movement, the ice moved through it. The depth of moving ice is one of the determinants of its velocity, and because of the greater depth of ice in valleys, its motion here was more rapid than on the uplands above, and its abrading action more powerful. Under these conditions the valleys were deepened and widened.

Where the courses of the valleys were transverse to the direction of ice movement, the case was different. The ice was too viscous to span the valleys, and therefore filled them. In this case it is evident that the greater depth of the ice in the valley did not accelerate its motion, since the ice in the valley-trough and that above it were in a measure opposed. If left to itself, the ice in the valley would tend to flow in the

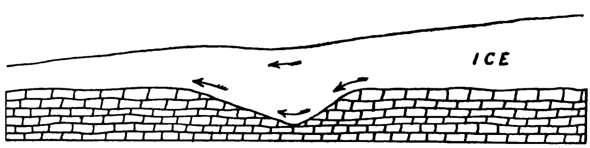

FIG. 6. Diagram showing effect on a valley of ice moving traversely across it.

direction of the axis of the valley. Shallow valleys crossed by the ice suffered most wear on the side opposing ice movements. (Fig. 6.) When deep, narrow valleys were transverse to the direction of ice ad-

vance, the ice that first entered them may have become stationary, forming a bridge over which the main mass of ice moved. (Fig. 7). In such cases the valley did not suffer much wear.

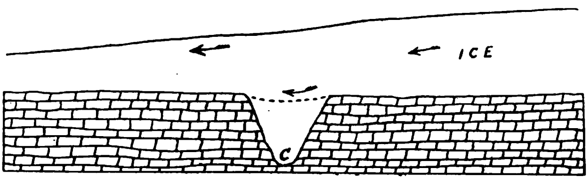

FIG. 7. Diagram to illustrate case where ice fills a valley (c) and the upper ice then moves on over the filling.

In general, the effort was to cut down prominences, thus tending to level the surface. But when it encountered valleys parallel to its movement they were deepened, thus locally increasing relief. Whether the reduction of the hills exceeded the deepening of the valleys, or whether the reverse was true, so far as corrasion alone is concerned, is uncertain. But whatever the effect of the erosive work of ice action upon the total amount of relief, the effect upon the contours was to make them more gentle. Not only were the sharp hills rounded off, but even the valleys which were deepened were widened as well, and in the process their slopes became more gentle. A river-erosion topography, modified by the wearing (not the depositing) action of the ice, would be notably different from the original, by reason of its gentler slopes and softer contours. (Figs. 4 and 5.) The great lobe of ice that moved southward in the Lake Michigan trough undoubtedly deepened that depression. The present bed of Lake Michigan is at places about 300 feet below sea level and much of the deepening below sea-level may be due to glacial erosion.

Deposition by the Ice—Effect on Topography—On melting, glacier ice leaves its bed covered with the debris which it gathered during its movement. Had this debris been equally distributed on and in and beneath the ice during its movement, and had the conditions of deposition been everywhere the same, the drift would constitute a mantle of uniform thickness over the underlying rock. Such a mantle of drift would not greatly alter the topography; it would simply raise the surface by an amount equal to the thickness of the drift, leaving elevations and depressions of the same magnitude as before, and sustaining the same relations to one another. But the drift carried by the ice, in what ever position, was not equally distributed during transportation, and the conditions under which it was deposited were not uniform, so that it produced more or less notable changes in the topography of the surface on which it was deposited.

The unequal distribution of the drift is readily understood. The larger part of the drift transported by the ice was carried in its basal portion; but since the surface over which the ice passed was variable, it yielded a variable amount of debris to the ice. Where it was hilly, the friction between it and the ice was greater than where it was plain, and the ice carried away more load. From areas where the surface

was overspread by a great depth of loose material favorably disposed for removal, more debris was taken than from areas where material in a condition to be readily transported was meager. Because of the topographic diversity and lithological heterogeneity of the surface of the country over which it passed, some portions of the ice carried much more drift than others, and when the ice finally melted, greater depths of drift were left in some places than in others. Not all of the material transported by the ice was carried forward until the ice melted. Some of it was probably carried but a short distance from its original position before it lodged. Drift was thus accumulating at some points beneath the ice during its onward motion. At such points the surface was being built up; at other points, abrasion was taking place, and the surface was being cut down. The drift mantle of any region does not, therefore, represent simply the material which was on and in and beneath the ice of that place at the time of its melting, but it represents, in addition, all that lodged beneath the ice during its movement.

The constant tendency was for the ice to carry a considerable part of its load forward toward its thinned edge, and there to leave it. It follows that if the edge of the ice remained constant in position for any considerable period of time, large quantities of drift would have accumulated under its marginal portion, giving rise to a belt of relatively thick drift. Other things being equal, the longer the time during which the position of the edge was stationary, the greater the accumulation of drift. Certain ridge-like belts where the drift is thicker than on either hand, are confidently believed to mark the position where the edge of the ice-sheet stood for considerable periods of time.

The morainic belt of this type that is nearest the region under consideration is known as the Valparaiso moraine. This moraine borders Lake Michigan at a distance of about 20 miles from the shoreline. It marks the maximum position of the Lake Michigan lobe during the later phase of the Wisconsin or last glacial epoch. West of Waukegan this moraine crosses the main line of the Chicago and Northwestern railroad between the towns of Cary and Barrington. Farther south, Glen Elyn, Hinsdale and Lemont are located in this hilly belt and in Indiana the city of Valparaiso, from which the moraine received its name, is located within the belt.

Because of the unequal amounts of material carried by different parts of the ice, and because of the unequal and inconstant conditions of deposition under the body of the ice and its edge, the mantle of drift has a very variable thickness; and a mantle of drift of variable thickness cannot fail to modify the topography of the region it covers. The extent of the modification will depend on the extent of the variation. This amounts in the aggregate to hundreds of feet. The continental ice sheet, therefore, modified the topography of the region it covered, not only by the wear it effected, but also by the deposits it made.

In some places it chanced that the greater thicknesses of drift were left in the position formerly marked by valleys. Locally the body of drift was so great that valleys were completely filled, and therefore completely obliterated as surface features. Less frequently, drift not

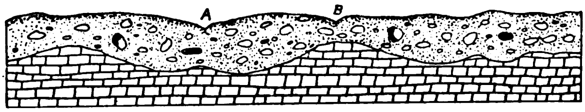

FIG. 8. Diagrammatic section showing relation of drift to underlying rock, where the drift is thick, relative to the relief of the rock. A and B represent the location of post-glacial valleys.

only filled the valleys but rose even higher over their former positions than on either side. In other places the greater depths of drift, instead of being deposited in the valleys, were left on pre-glacial elevations, building them up to still greater heights. In short, the mantle of drift of unequal thickness was laid down upon the rock surface in such a manner that the thicker parts sometimes rest on hills and ridges, sometimes on slopes, sometimes on plains, and sometimes in valleys.

These relations are suggested by (Fig. 8 and 9). From them it will be seen that in regions where the thickness of the drift is great, relative to the relief of the underlying work, the topography may be completely changed. Not only may some of the valleys be obliterated by being filled, but some of the hills may be obliterated by having the lower land between them built up to their level. In regions where the thickness of the drift is slight, relative to the relief of the rock beneath, the hills cannot be buried, and the valleys cannot be completely filled, so that the relative positions of the principal topographic features will remain much the same after the deposition of the drift, as before (Fig. B).

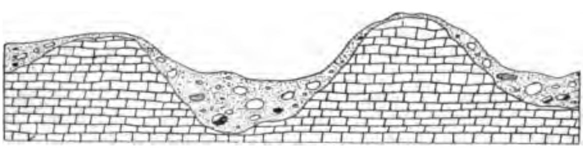

FIG. 9. Diagrammatic section showing relation of drift to underlying rock where the drift is thin relative to the relief of the underlying rock.

In case the pre-glacial valleys were filled and the hills buried, the new valleys which the surface waters will in time cut in the drift surface will have but little correspondence in position with those which existed before the ice incursion. A new system of valleys, and therefore a new system of ridges and hills, will be developed, in some measure independent of the old. These relations are illustrated by Fig. 8.

Inequalities in the thickness of drift lead to a still further modification of the surface. It frequently happened that in a plane or nearly plane region, a slight thickness of drift was deposited at one point, while all about it much greater thicknesses were left. The area of thin drift would then constitute a depression, surrounded by a higher surface built up by the thicker deposits. Such depressions would at first have no outlets, and are therefore unlike the depressions shaped by rain and river erosion. The presence of depressions without outlets is one

of the marks of a drift-covered (glaciated) country. In these depressions water may collect, forming lakes or ponds, or in some cases only marshes and bogs.

The thickness of drift in the Evanston-Waukegan region is so great that the underlying rock topography is obliterated, and the rolling surface of the upland is due entirely to the distribution of the drift. There are numerous undrained depressions in the upland surface, and many of them contain ponds or marshes, especially during the spring.

In the farming district about Waukegan, there are numerous wells 75 to 100 feet deep in which bed-rock was not reached. Southwest of Lake Forest, on L. F. Swift's farm, there is a well 280 feet deep in drift and one mile farther west another well down 180 feet, without striking bed-rock.

In the following cases rock was reached, and therefore the thickness of drift determined:

1. At Mrs. M. J. Durkin's, three miles north of Waukegan, bed-rock was reached at 150 feet. The well is 175 feet deep.
2. At H. W. Ferry's, four and one-half miles north of Waukegan, bed-rock was reached at 128 feet.
3. Three miles west of Waukegan on a farm owned by Mrs. Durkin, bed-rock was reached at 90 feet.
4. At L. F. Swift's artesian well, Lake Forest, bed-rock was reached at 212 feet. The well is 989 feet deep.
5. At Mr. Booth's well, a quarter of a mile southwest of Mr. Swift's, bed-rock was reached at about 280 feet.
6. At C. B. Farwell's artesian well, Lake Forest, rock was struck at 160 feet*
7. In Highland Park rock was struck at 160 to 175 feet.†
8. At Mr. Lloyds' artesian well, in the north part of Winnetka, rock was struck at 150 feet.*
9. In Ravina a well reaches bed-rock at 164 feet.*
10. At Dr. Oliver Marcy's, South Evanston, bed-rock was found 72 feet below the surface.†

The average thickness of drift in the upland region is probably about 150 feet, and in the lake plain areas from 50 to 75 feet. In most places the surface of the rock is well below the surface of the lake.

Direction of Ice Movement—The direction in which glacier ice moved may be determined in various ways, even after the ice has disappeared. The shapes of the rock hills over which the ice passed (p. 12), the direction from which the materials of the drift came, the striations on bed-rock, and the course of the margin of the drift, are all used in making such determinations. From the course of the drift margin, the general direction of movement may be inferred when it is remembered that the tendency of glacier ice on a plane surface is to move at right angles to its margin.

For the exact determination of the direction of ice movement, recourse must be had to the striæ on the bed-rock. Were the striated rock surface perfectly plane, and were the striæ even lines, they would only tell that the ice was moving in one of two directions. But the rock surface is not usually perfectly plane, nor the striæ even lines,

* From the Pleistocene Features and Deposits of the Chicago Area; Frank Leverett. Bull. 2, Geol. and Nat. Hist. Surv., Chicago Acad. of Sci.

† Frank Leverett, in 17th Ann. Rept. U. S. Geol. Surv., Pt. II, P. 800.

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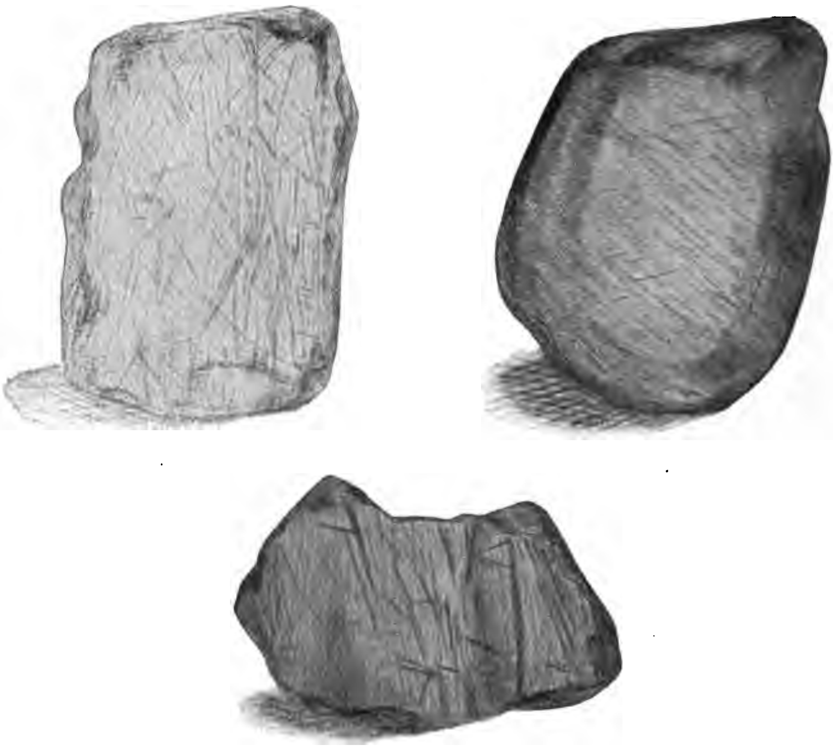

Fig. A. Glaciated stones showing both form and striae. (Matz.)
[Courtesy of Wisconsin Geol. Nat. Hist. Surv.]

Fig. B. Limestone bowlder in north fork of Pettibone Creek, North Chicago.

Fig. C. Igneous bowlder at Northwestern Railway station, Waukegan.

and between the two directions which lines alone might suggest, it is usually possible to decide. The minor prominences and depressions in the rock surface were shaped according to the same principles that govern the shaping of hills (Fig. 5) and valleys (Fig. 6); that is, the proximal or stoss (struck) sides of the minor prominences, and the distal sides of small depressions suffered the more wear. With a good compass, the direction of the striæ may be measured to within a fraction of a degree, and thus the direction of ice movement in a particular place be definitely determined.

In the Evanston-Waukegan area the source of the material in the drift is the only guide in determining the direction from which the ice came, but from the study of a larger area it is known that the ice which invaded this region moved southward through the Lake Michigan trough, spreading westward over the bordering lands on the west side of the lake.

Effect of Topography on Movement—The effect of glaciation on topography has been outlined, but the topography in turn exerted an important influence on the direction of ice movement. The extreme degree of topographic influence is seen in mountain regions like the Alps, where most of the glaciers are confined strictly to the valleys.

As an ice sheet invades a region, it advances first and farthest along the lines of least resistance. In a rough country with great relief, tongues or lobes of ice push forward in the valleys, while the hills or other prominences tend to hold back or divide the onward moving mass. The edge of an ice sheet in such a region would be irregular. The marginal lobes of ice occupying the valleys would be separated by re-entrant angles marking the sites of hills and ridges.

As the ice advanced southwestward from the Laborador center of accumulation (Fig. 3) one lobe followed the Lake Superior trough and another lobe moved through the Lake Michigan trough. There was, therefore, relatively less ice to move directly southwestward over the Wisconsin region. These conditions help to account for the driftless or unglaciated region in the southwestern portion of Wisconsin. The Green Bay lobe (Fig. 30) developed on the west flank of the Lake Michigan lobe, and was led off by the depression in that direction.

GLACIAL DEPOSITS.

General Characteristics—When the ice of the continental glacier began its motion, it carried none of the stony and earthy debris which constitutes the drift. These materials were derived from the surface over which the ice moved.

From the method by which it was gathered, it is evident that the drift of any locality may contain fragments of rock of every variety which occurs along the route followed by the ice which reached that locality. When the ice had moved far, and when there were frequent changes in the character of the rock constituting its bed, the variety of materials in the drift is great. The heterogeneity of the drift arising from the diverse nature of the rocks which contributed to it is *litho-*

logical heterogeneity—a term which implies the commingling of materials derived from different rock formations. Thus it is common to find pieces of sandstone, limestone, quartzite, granite, gneiss, schist, etc., intimately commingled in the drift, wherever the ice which produced it passed over formations of these several sorts of rock. Lithological heterogeneity is one of the notable characteristics of glacial formations.

In the Evanston-Waukegan region the glacial sands commonly contain particles of quartz, feldspar, hornblende, augite, pyrite, and magnetite. When the sand is dry, the magnetite may be easily withdrawn from the other grains by a magnet. The pebbles and large stones of the drift include the following:

1. Red sandstone, compact and fine grained.
2. Yellow sandstone, coarse grained and friable.
3. Mottled sandstone, red and yellow.
4. Brown sandstone, rich in iron oxides.
5. Red quartzite, compact and hard but with sand grains noticeable.
6. Conglomerate, composed of sand and gravel and due to local cementation.
7. White limestone, compact and hard.
8. Fossiliferous limestone, composed largely of shells.
9. Marble, finely crystalline.
10. Shale, soft, with layers that part easily.
11. Slate, hard, with layers that part easily.
12. Red granite, pink and red feldspar crystals predominating.
13. Gray granite, white feldspar crystals predominating.
14. Syenite, like granites but with little or no quartz.
15. Diorite, quartz and feldspar present but black hornblende crystals predominating.
16. Gabbro, quartz and feldspar present but black pyroxene crystals predominating.
17. Porphyry, quartz phenocrysts most common.
18. Basalt, dark green or black and very finely crystalline.
19. Gneiss, banded.
20. Schist, more closely banded than gneiss, and often appears to be in layers.
21. Quartz, white, glassy and very hard.
22. Jaspar, red, fine textured and very hard.
23. Flint, gray or black, brittle, glassy and very hard.
24. Chert, white, brittle, and very hard.
25. Pyrite, light yellow and heavy.

Collections of these sorts of rock may easily be made almost anywhere on the beach, but stony material is most accessible near North Chicago, and southward to Lake Bluff, and near Glencoe and Lakeside.

Another characteristic of the drift is its *physical heterogeneity*. As first gathered from the bed of moving ice, some of the material of the drift was fine and some coarse. The tendency of the ice in all cases was to reduce its load to a still finer condition. Some of the softer materials, such as soft shale, were crushed or ground to powder, forming what is commonly known as clay. Clayey (fine) material is likewise produced by the grinding action of ice-carried bowlders upon the rock-bed, and upon one another. Other sorts of rock, such as soft sandstone, were reduced to the physical condition of sand, instead of clay, and from sand to bowlders all grades of coarseness and fineness are represented in the glacial drift.

The two largest bowlders known to the writer, in this region, are:

1. **A gray magnesian limestone fully 8 feet in length and located on the beach near Glencoe. This bowlder is near the base of the cliff and a few rods north of the east-west road nearest the Northwestern railroad station. The upper surface is beautifully striated.**
2. **A gray magnesian limestone bowlder in the North Branch of Pettibone creek. This rock is 15 feet in length and may be found by following the creek down stream from North Chicago. It is on the left side and about 20 feet above the water (Fig. B, Plate I). The surfaces of this bowlder are also striated.**

The limestone bowlders are of relatively local origin and may have been carried but a few miles. The igneous rock at Waukegan has come at least 300 miles, and may have come much farther.

Since the ice does not assort the material which it carries, as water does, the clay, sand, gravel and bowlders will not, by the action of the ice, be separated from one another. They are therefore not stratified. As left by the ice, these phyically heterogeneous materials are confussedly commingled. The finer parts constitute a matrix in which the coarser are embedded.

Physical heterogeneity (Plate II), therefore, is another characteristic of glacial drift. It is not to be understood that the proportions of these various physical elements, clay, sand, gravel and bowlders, are constant. Locally any one of them may predominate over any or all the others to any extent.

Since lithological and physical heterogeneity are characteristics of glacial drift, they together afford a criterion which is often of service in distinguishing glacial drift from other surface formations. It follows that this double heterogeneity constitutes a feature which can be utilized in determining the former extension of existing glaciers, as well as the former existence of glaciers where glaciers do not now exist.

Another characteristic of glacial drift, and one which clearly distinguishes it from all other formations with which it might be confounded, is easily understood from its method of formation. If the ice in its motion holds down rock debris upon the rock surface over which it passes with such pressure as to polish and striate the bed-rock, the material carried will itself suffer wear comparable to that which it inflicts. Thus the stones, large and small, of glacial drift, will be smoothed and striated. This sort of wear on the transported blocks of rock, is effected both by the bed-rock reacting on the bowlders transported over it, and by bowlders acting on one another in and under the ice. The wear of bowlders by bowlders is effected wherever adjacent ones are carried along at different rates. Since the rate of motion of the ice is different in different parts of the glacier, the mutual abrasion of transported materials is a process constantly in operation. A large proportion of the transported stone and blocks of rock may thus eventually become striated.

From the nature of the wear to which the stones are subjected when carried in the base of the ice, it is easy to understand that their shapes must be different from those of water-worn materials. The latter are rolled over and over, and thus lose all their angles and assume a more

or less rounded form. The former, held more or less firmly in the ice, and pressed against the underlying rock or rock debris as they are carried slowly forward, have their faces planed and striated. The planation and striation of a stone need not be confined to its under surface. On either side or above it other stones, moving at different rates, are made to abrade it, so that its top and sides may be planed and scored. If the ice-carried stones shift their positions, as they may under various circumstances, new faces will be worn. The new face thus planed off may meet those developed at an earlier time at sharp angles, altogether unlike anything which water-wear is capable of producing. The stone thus acted upon shows a surface bounded by planes and more or less beveled, instead of a rounded surface such as water-wear produces. We find, then, in the shape of the bowlders and smaller stones of the drift, and in the markings upon their surfaces, additional criteria for the identification of glacier drift (Plate I, Fig. A).

The characteristics of glacial drift, so far as concerns its constitution, may then be enumerated as, (1) its lithological, and (2) physical heterogeneity, (3) the shapes, and (4) the markings of the stones of the drift. In structure, the drift which is strictly glacial, is unstratified.

In the broadest sense of the term, all deposits made by glacier ice are *moraines*. Those made beneath the ice and back from its edge constitute the *ground moraine*, and are distinguished from the considerable marginal accumulations which, under certain conditions, are accumulated at or near the margin. These marginal accumulations are *terminal moraines*. Associated with the moraines which are the deposits of the ice directly, there are considerable bodies of stratified gravel and sand, the structure of which shows that they were laid down by water. This is to be especially noted, since lack of stratification is popularly supposed to be the especial mark of the formations to which the ice gave rise.

These deposits of stratified drift lie partly beyond the terminal moraine, and partly within it. They often sustain very complicated relations both in the ground and terminal moraines. The drift as a whole is therefore partly stratified and partly unstratified. Structurally the two types and thoroughly distinct, but their relations are often most complex, both horizontally and vertically.

GROUND MORAINE.

Distribution—The ground moraine constitutes the great body of the glacial drift. *Bowlder clay,* a term descriptive of its constitution in some places, and *till,* are other terms often applied to the ground moraine. The ground moraine consists of all the drift which lodged beneath the ice during its advance, all that was deposited back from its edge while its margin was farthest south, and most of that which was deposited while the ice was retreating. From this mode of origin it is readily seen that the ground moraine should be essentially as widespread as the ice itself. Locally, however, it failed of deposition. Since it constitutes the larger part of the drift, the characteristics already

enumerated as belonging to drift in general are the characteristics of the till. Wherever obstacles to the progress of the ice lay in its path, there was a chance that these obstacles, rising somewhat into the lower part of the ice, would constitute barriers against which debris in the lower part of the ice would lodge. It might happen also that the ice, under a given set of conditions favoring erosion, would gather a greater load of rock-debris than could be transported under the changed conditions into which its advance brought it. In this case, some part of the load would be dropped and over-ridden. Especially near the margin of the ice where its thickness was slight and diminishing, the ice must have found itself unable to carry forward the loads of debris which it had gathered farther back where its action was more vigorous. It will be readily seen that if not earlier deposited, all material gathered by the under surface of the ice would ultimately find itself at the edge of the glacier, for given time enough, ablation will waste all that part of the ice occupying the space between the original position of the debris, and the margin of the ice. Under the thinned margin of the ice, however, considerable accumulations of drift must have been taking place while the ice was advancing. While the edge of the ice sheet was advancing into territory before uninvaded, the material accumulated beneath its edge at one time, found itself much farther from the margin at another and later time. Under the more forcible ice action back from the margin, the earlier accumulations, made under the thin edge, were partially or wholly removed by the thicker ice of a later time, and carried down to or toward the new and more advanced margin. Here they were deposited, to be in turn distributed and transported still farther by the farther advance of the ice.

Since in its final retreat the margin of the ice must have stood at all points once covered by it, these submarginal accumulations of drift must have been made over the whole country once covered by the ice. The deposits of drift made beneath the marginal part of the ice during its retreat, would either cover the deposits made under the body of the ice at an earlier time, or be left alongside them. The constitution of the two phases of till, that deposited during the advance of the ice, and that deposited during its retreat, is essentially the same, and there is nothing in their relative positions, to sharply differentiate them. They are classed together as *subglacial till.*

Subglacial till was under the pressure of the overlying ice. In keeping with these conditions of accumulation, the till often possesses a firmness suggestive of great compression. Where its constitution is clayey it is often remarkably tough. Where this is the case, the quality here referred to has given rise to the suggestive name "hard pan." Where the constitution of the till is sandy, rather than clayey, this firmness and toughness are less developed, or may be altogether wanting, since sand cannot be compressed into coherent masses like clay.

Constitution—The till is composed of the more or less comminuted materials derived from the land across which the ice passed. The soil and all the loose materials which covered the rock entered into its composition. Where the ice was thick and its action vigorous, it not

only carried away the loose material which it found in its path, but, armed with this material, it abraded the underlying rock, wearing down its surface and detaching large and small blocks of rock from it. It follows that the constitution of the till at any point is dependent upon the nature of the soil and rock from which it was derived.

If sandstone be the formation which has contributed most largely to the till, the matrix of the till will be sandy. Where limestone instead of sandstone made the leading contribution to it, the till has a more earthy or clayey matrix. Any sort of rock which may be very generally reduced to a fine state of division under the mechanical action of the ice, will give rise to clayey till.

The nature and the number of the bowlders in the till, no less than the finer parts, depend on the character of the rock overridden. A hard and resistant rock, such as quartzite, will give rise to more bowlders in proportion to the total amount of material furnished to the ice, than will softer rock. Shale or soft sandstone, possessing relatively slight resistance, will be much more completely crushed. They will, therefore, yield proportionately fewer bowlders than harder formations, and more of the finer constituents of till.

The bowlders taken up by the ice as it advanced over one sort of rock and another, possessed different degrees of resistance. The softer ones were worn to smaller dimensions or crushed with relative ease and speed. Bowlders of soft rock, are therefore, not commonly found in any abundance at great distances from their sources. The harder ones yielded less readily to abrasion, and were carried much farther before being destroyed, though even such must have suffered constant reduction in size during their subglacial journey. In general it is true that boulders in the till, near their parent formations, are larger and less worn than those which have been transported great distances.

The ice which covered this region had come a great distance and had passed over rock formations of many kinds. The till therefore contains elements derived from various formations; that is, it is lithologically heterogeneous. This heterogeneity can not fail to attract the attention of one examining any of the many exposures of drift along the lake shore or the stones lodged on the beach.

In general the till of any locality is made up largely of material derived from the formations close at hand. This fact seems to afford sufficient warrant for the conclusion that a considerable amount of deposition must have gone on beneath the ice during its movement, even back from its margin. To take a concrete illustration, it would seem that the drift of the Evanston-Waukegan region should have had a larger contribution than it has of material derived from Canadian territory, if material once taken up by the ice was all or chiefly carried down to its thinned edge before deposition. The fact that so little of the drift came from these distant sources would seem to prove that a large part of the material moved by the ice, is moved a relatively short distance only. The ice must be conceived of as continually depositing parts of its load, and parts which it has carried but a short distance, as it takes up new material from the territory newly invaded. In keeping with the character of till in general, that of this region was derived largely from limestone.

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Fig. A. Abandoned clay pit near Fort Sheridan. [Courtesy of the C. & N. W. Ry.]

Fig. B. Sketch of ground moraine topography.

Fig. C. Sketch of terminal moraine topography.

Topography—The topography of the ground moraine is in general the topography already described (pp. 13-15) in considering the modification of preglacial topography effected by ice deposition. As left by the ice, its surface was undulating. (Plate II, Fig. B.) The undulations did not take the form of hills and ridges with intervening valleys, but of swells and depressions standing in no orderly relationship to one another. Undrained depressions are found in the ground moraine, but they are, as a rule, broader and shallower than the "kettles" common to terminal moraines (Plate II, Fig. C.) It is in the broad, shallow depressions that many of the lakes and more of the marshes of southeastern Wisconsin are located.

The rolling, undulating topography characteristic of ground moraines is well shown just west of the Chicago and Northwestern road between Glencoe and Waukegan. North of Waukegan, the upland is typical ground moraine, but the lowland is an ancient lake flat.

When the entire morainic area from the shore of Lake Michigan to the Des Plaines river is considered, it is found to consist of three somewhat distinct north-south ridges* separated by lowlands of gently rolling topography. The west ridge decreases in height to the south, and dies out in a plain near Mont Clare in the southwestern part of Jefferson township. The southern terminus of the middle ridge is near the head of the Chicago river, and at the border of the former extension of the lake. The eastern ridge is the one with which we are chiefly concerned in the north shore region. This ridge extends from the northern boundary of the State southward to Winnetka, where it is intersected by the present lake shore. The most easterly of these ridges rises about 100 feet above the lake, a mile back from the shore. Its crest is followed by the C. & N. W. railway for some miles. These ridges still remain much as the ice left them. The time which has elapsed since the ice disappeared from the region has been too short for them to have been greatly changed. A bowlder train on the lake bottom was reported by Lyman Cooley, of the Chicago Drainage Commission as running southeastward for several miles from the terminus of this ridge, and Mr. Leverett thinks this may be the residue from the till ridge which has been cut away by the lake.† Aside from the ravines the upland of the Evanston-Waukegan region has a ground moraine topography. If the ravines were filled and the rolling upland extended eastward, descending gradually to the lake level, the surface as left by the ice would be essentially reproduced.

TERMINAL MORAINES.

Formation—The marginal portion of the ice sheet was more heavily loaded—certainly more heavily loaded relative to its thickness—than any other. Toward its margin, the thinned ice was constantly losing its transportive power, and at its edge this power was altogether gone. Since the ice was continually bringing drift down to this position and

* These ridges have been fully described by Leverett in "The Pleistocene Features and Deposits of the Chicago Area." Bull. 2, p. 42, Geol. and Nat. Hist. Surv., Chicago Acad. of Sci.

† For fuller discussion see Chicago Folio U. S. Geol. Surv., p. 6, by Wm. C. Alden.

leaving it there, the rate of drift accumulation must have been greater, on the average, beneath the edge of the ice than elsewhere.

Whenever, at any stage of its history, the edge of the ice remained essentially constant in position for a long period, the corresponding submarginal accumulation of drift was great, and when the ice melted, the former site of the stationary edge would be marked by a broad ridge or belt of drift, thicker than that on either side. Such thickened belts or drift are *terminal moraines.* It will be seen that a terminal moraine does not necessarily mark the terminus of the ice at the time of its greatest advance, but rather its terminus at any time when its edge was stationary or nearly so.

These submarginal moraines are often made of materials identical with those which constitute the ground moraine. Such materials as were carried on the ice were dropped at its edge when the ice which bore them melted from beneath. If the surface of the ice carried many bowlders, many would be dropped along the line of its edge wherever it remained stationary for any considerable period of time. A terminal moraine, therefore, embraces (1) the thick belt of drift accumulated beneath the edge of the ice while it was stationary, or nearly so; and (2) such debris as was carried on the surface of the ice and dumped at its margin. In general the latter is relatively unimportant.

Topography of terminal moraines—The most distinctive feature of a terminal moraine is not its ridge-like character, but its peculiar topography. In general, it is marked by depressions without outlets, associated with hillocks and short ridges comparable in dimensions to the depressions (Plate II, Fig. C). Both elevations and depressions are, as a rule, more abrupt than in the ground moraine. In the depressions there are many marshes, bogs, ponds and small lakes. The shapes and the abundance of round and roundish hills have locally given rise to such names as "The Knobs," "Short Hills," etc. Elsewhere the moraine has been named the "Kettle Range," from the number of kettle-like depressions in its surface. It is to be kept in mind that it is the association of the "knobs" and "kettles," rather than either feature alone, which is the distinctive mark of terminal moraine topography. Terminal moraines have no distinct development within the area here described, and are mentioned here only for general contrast with the ground moraine.

STRATIFIED DRIFT.

While it is true that glacier ice does not distinctly stratify the deposits which it makes, it is still true that a very large part of the drift for which the ice of the glacial period was directly or indirectly responsible is stratified. That this should be so is not strange when it is remembered that most of the ice was ultimately converted into running water, just as the glaciers of today are. The relatively small portion which disappeared by evaporation was probably more than counterblanced, at least near the margin of the ice, by the rain which fell upon it. It can not be considered an exaggeration, therefore, to say

that the total amount of water which operated on the drift, first and last, was hardly less than the total amount of the ice itself. The drift deposited by the marginal part of the ice was affected during its deposition, not only by the water which arose from the melting of the ice which did the depositing, but by much water which arose from the melting of the ice far back from the margin. The general mobility of the water, as contrasted with the ice, allowed it to concentrate its activities along those lines which favored its motion, so that different portions of the drift were not affected equally by the water of the melting ice.

All in all, it will be seen that the water must have been a very important factor in the deposition of the drift, especially near the margin of the ice. But the ice sheet had a marginal belt throughout its whole history, and water must have been active and effective along this belt, not only during the decadence of the ice sheet, but during its growth as well. It is further to be noted that any region of drift stood good chance of being operated upon by the water after the ice had departed from it, so that in regions over which topography directed drainage after the withdrawal of the ice, the water had the last chance at the drift, and modified it in such a way and to such an extent as circumstances permitted.

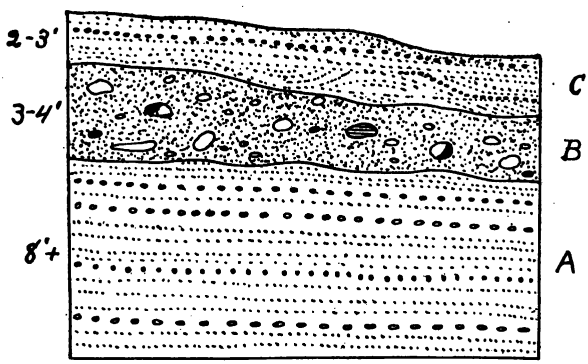

FIG. 10. Section showing relations of stratified drift (a), till (b), and beach sands and gravels (c), as exposed at Winthrop Harbor.

There are no clearly defined areas of stratified drift in the upland part of the Evanston-Waukegan region, but within the drift exposures along the lake cliff, lenses or patches of stratified drift may be seen frequently.

At Winthrop Harbor the section represented in Fig. 10 is exposed along the main north-south road. The stratified drift at the base was deposited beyond the ice edge during its advance, or during some temporary period of recession. After the assorted material was laid down, the ice advanced over this particular area, and deposited a layer of till. The sands and gravels above the unstratified drift of the section are beach formations of the Glenwood stage of Lake Chicago.

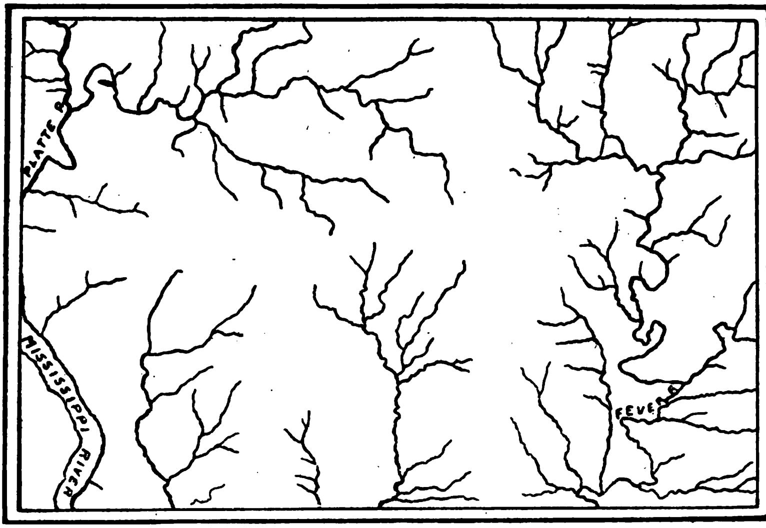

FIG. 11. Drainage in the driftless area. The absence of ponds and marshes is to be noted. (Courtesy of Wisconsin Geol. Nat. Hist. Surv.)

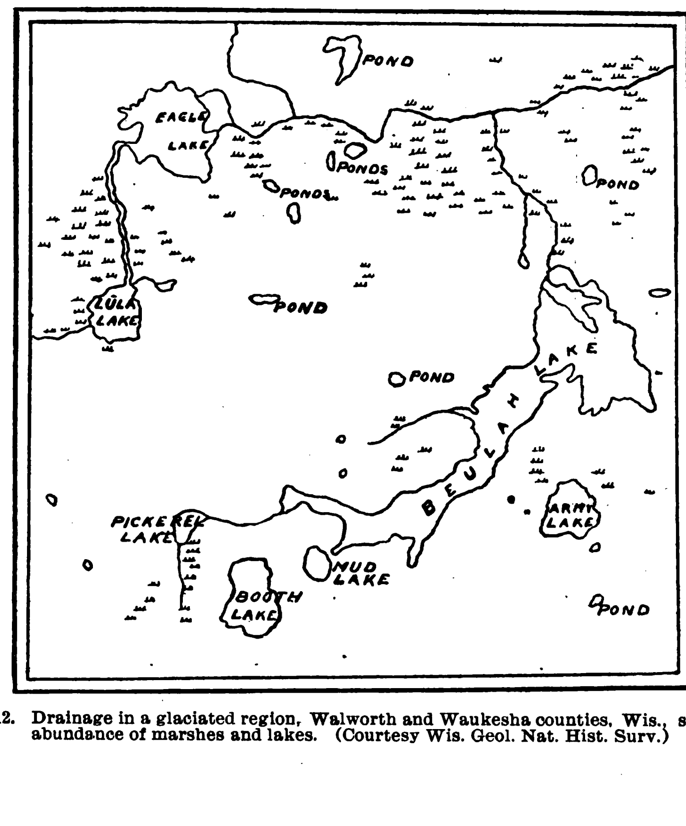

FIG. 12. Drainage in a glaciated region, Walworth and Waukesha counties, Wis., showing abundance of marshes and lakes. (Courtesy Wis. Geol. Nat. Hist. Surv.)

Stratified drift covers much of the surface below an altitude of 640 feet. (See topographic maps.)

To appreciate the changes which glaciation effected in this region, it may be pointed out that both the topography and the surface material of unglaciated regions are very different from those of this region. The driftless or unglaciated area in the northwestern part of the State already referred to, has a surface shaped almost wholly by running water. All depressions are valleys and have outlets. The region is therefore well-drained, and so without the ponds, marshes, etc., which often characterize recently glaciated areas (Figs. 11 and 12).

Unglaciated surfaces are generally overspread by a mantle of soil and earth which has resulted from the decomposition of the underlying rock. This earthy material sometimes contains fragments and even large masses of rock like that beneath. These fragments and masses escaped disintegration because of their greater resistance, while the surrounding rock was destroyed. This mantle rock grades from fine material at the surface down through coarser, until the solid rock is reached, the upper surface of the rock being often ill-defined (Fig. 13). The thickness of the mantle is approximately constant in like topographic situations where the underlying rock is uniform. The residual soils are made up chiefly of the insoluble parts of the rock from which they are derived, the soluble parts having been removed in the process of disintegration.

FIG. 13. Diagram showing the relation of residual soil to the underlying rock from which it is derived. (Courtesy of U. S. Geol. Surv.)

With these residuary soils of the driftless area, the mantle rock of glaciated tracts is in sharp contrast. Here, as already pointed out, the material is diverse, having come from various formations and from widely separated sources. It contains the soluble as well as the insoluble parts of the rock from which it was derived. In it there is no suggestion of uniformity in thickness, no regular gradation from fine to coarse from the surface downward. The average thickness of the drift is also much greater than that of the residual earths. Further, the contact between the drift and the underlying rock surface is usually a definite surface. (Compare Figs. 8 and 13.)

THE PRESENT SHORE LINE.

(BY J. W. GOLDTHWAIT.)

EVOLUTION SEEN IN SHORE LINE TOPOGRAPHY.

The land forms peculiar to shore lines depend for their existence upon those movements of the waters which are initiated by the winds. If there were no winds, such a lake as Lake Michigan would be practically without waves and currents, a dead, inert sheet of water; and its shores would be without strength and character. Shore forms, like all other forms, are changing, living objects in so far as solar energy is expended upon them through the so-called geological agents—in this case waves and currents. On sea shores the tides are also of importance in determining and constantly modifying the shore topography.

On a day when the air is calm or when a light off-shore breeze is blowing and the lake is smooth, the agents just mentioned are temporarily inactive. On such a day one may stand on the bluff overlooking Lake Michigan at any point on the north shore, and as far out as can be seen the lake water is unclouded by sediment. At the base of the bluff is a bare beach of sand or gravel, against the border of which the small waves are lapping in a weak, desultory way. It is scene of inactivity. At such a time the evolution of shore forms would not be evident. But when a strong east wind has roused the waves to violence, whitecaps dot its roughened surface, and a strong surf is breaking near the shore and sweeping back and forth in rhythmic fashion at the base of the cliff, nearly or quite concealing the beach platform below. The waves are gnawing into the base of the bluff, exposing the fresh, blue clay, where formerly may have been a turf-covered slope. From the face of the bluff, thus steepened, great masses of clay may be seen slipping down to the water's edge, where they are further broken up by the waves and thoroughly separated into the constituent boulders, gravel, sand and mud. Trees toppling from the brink of the bluff emphasize the rapidity of the process (Plate III, Fig. A). The waters of the lake for a long way out are muddy with suspended sediment. By oblique advances and retreats of the waves upon the shore, gravel is being washed up and down the beach in zig zag fashion along the shore. It is an easy inference that in the shallow water just beyond, sand is being drifted steadily leeward. The lake is now in action, and the shore form in process of development. One returns from such a view with a ready belief in doctrine of change or evolution as applied to shore forms.

AGENTS AT WORK ALONG SHORE LINES.*

The Waves—When a strong wind sweeps across the surface of a body of water, it communicates energy which sets every water particle oscillating in an approximately circular orbit—the basis of the phenomenon which we call a wave. In the normal off-shore wave, or in any normal wave away from the shore, there is very little forward advance of the water; each particle returns nearly or quite to its original position, so that the wave has well been called "a traveling shape of water." In the form of wave known as the swell, which moves in deep water, outside the area which is under the direct influence of the wind, the orbits of the particles of water are closed. There is no permanent advance of the water. But in the wind wave, the forward movement of the particle is always slightly in excess of the return movement, so that each particle describes a spiral rather than an ellipse, and there is generated a slow current which moves forward following the waves. Figure 14 shows how the particles move

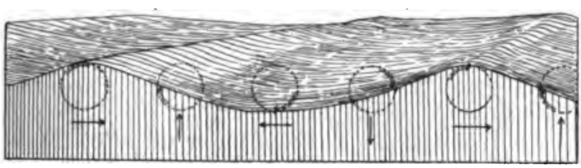

FIG. 14. Diagram showing the movement of particles in a wave. The waves are moving from left to right.

in different parts of a wave, forward in the crest, backward in the trough, upward in front of the crest and downward behind it. The orbital motion of the particle is less rapid than the wind; the advance of the wave is even slower, and that of the wind driven current is still slower. By transmission downward, these motions are extended into deep water, but with rapidly diminishing effect. The deeper the water, the less are the movements embarrassed by friction on the bottom, the larger will be the waves and the stronger the currents. On the open ocean, wind waves are sometimes fifty feet high and 1,500 feet long, measured from crest to crest; but these are exceptional. On Lake Michigan the waves exceptionally attain a height of twenty feet.

The crest of a wave is always sharper than the trough, for the wave assumes the form of a trochoid curve, such as is described by a point within a circle which rolls on a horizontal line. (See Figure 15 H.) The sharpness of the crest is exaggerated when the wave length is shortened or its height increased. Compare, for instance, Figures 15, 16, 17 and 18.

* In the preparation of what follows regarding waves and their work the writer has drawn freely from Gilbert's paper on "The Topographic Features of Lake Shores," U. S. Geol. Surv., 5th Ann. Rept., pp. 69-123, 1885; and chapter 2 in Fenneman's "Lakes of Southeastern Wisconsin," Wis. Geol. and Nat. Hist. Surv. Bull. 8, 1902.

Fig. 15. Series of particles in their orbits. The circles represent the orbits of the particles which revolve from left to right. At any given moment each particle is advanced in its orbit 54 degrees more than its neighbor on the right. The curved line connecting these simultaneous positions of the particles represents the form of the wave. (After Fenneman.)

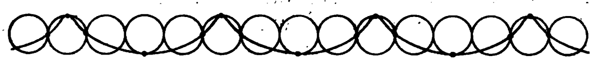

Fig. 16. The phasal difference of the particles has been increased from 45° to 90°. The crests of the waves thus become sharper. (After Fenneman.)

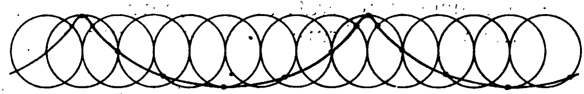

Fig. 17. The orbits have been increased to twice their former size; but the phasal difference is the same as in fig. 15. (After Fenneman.)

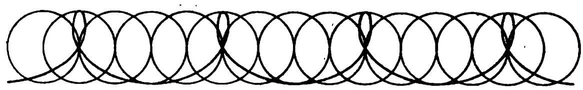

Fig. 18. By an increase both in the phasal difference of the particles and in the size of the orbits, a curve is developed, suitable for breakers. (After Fenneman.)

In Figure 15 various positions of a series of neighboring particles in the waves in their respective orbits are shown, the phasal difference of the particles being 45°. The surface of the wave which passes through these particles forms a low trochoid curve. In Figure 16 the wave has been shortened by increasing the difference in phase of the particles to 90°; and the trochoid is more pronounced in form than before, with sharper crest and flatter troughs. In Figure 17 the waves' length is like that of the first, but the amplitude of the orbital motion has been increased, and as a consequence the contrast between the crest and trough exaggerated. In Figure 18 the shortening and increase of amplitude has gone so far as to develop a trochoid curve that has loops in place of cusps—the condition for breaking waves. White caps are an expression of such a curve as the last, developed when the amplitude of the wave is increased more rapidly than its length by a wind of fast increasing strength.

When a wave approaches a shelving shore, reaching shallower and shallower water, its form is very considerably changed: (1). The wave becomes higher; for the transmission of energy to a smaller amount of water gives to each particle an increased orbital movement; (2). The wave is shortened, for increased friction diminishes the velocity of orbital motion of every particle, and this means a greater differential movement between the neighboring particles (compare

Figures 15 and 16; (3). The crest becomes steeper and sharper, the result of shortening the wave; and (4) the crest becomes a symmetrical, steeper in front than behind, because the forward motion in the crest, where the water is deeper, is more rapid than the backward motion in the trough, where water is shallower.

These changes of form become more and more marked, finally resulting in the breaking of the wave. The crest is thrown forward with a curling front, and the water foams and tosses with the confusion of oscillatory and translatory movements, for the sudden plunge of the broken crest starts new waves of translation or "solitary waves," which are quite different in nature from waves of oscillation. In the wave of translation each particle is carried forward in a semi-ellipse, those at the bottom moving as far as those at the surface.

Waves of translation are very efficient in sweeping material ashore. Since breakers usually form close to the water's edge, translatory waves are usually of short range and consist merely of a forward dash or "swash" of the wave to the crest of the beach. If, however, the incoming wind-waves break far off shore, as on a very shallow bottom, the diminution of height may permit them to re-form in conjunction with the translatory waves, and to run ashore until finally they break again. Translatory waves, where uncombined with oscillatory waves, are easily distinguished by their extremely broad and flat troughs, and narrow, sharp crests. The on-shore dash of the broken wave is followed by a return wash of the water down the beach slope to the point where it meets the next incoming wave of translation. Thus there is between the breakers and the water's edge a zone where material is shifted back and forth by opposed rhythmic movements. Under different conditions of shore profile, wave force, etc., either the inward or the outward action may be favored, and the erosion or deposition determined.

Undertow—The return flow of the broken wave gives rise to a permanent outgoing movement known as the "undertow." In a more comprehensive way, the undertow may be thought of as the means by which all water moved ashore by the wind-driven currents and by the waves of translation finds its way back to deep water. Instead of being a steady movement, it is a pulsating one, markedly so just outside the breaker line, because of the continual passage of oscillatory waves above it, and the alternate coöperation and opposition of those oscillations. Close to the breaker line, indeed, the on-shore translatory motion may counter-balance the undertow, and these conditions are favorable for deposition of material from both the off-shore and the on-shore forces. The pulsating nature of the undertow greatly increases its ability to transport waste seaward, for by hundreds of repeated jerks, a pebble which would be immovable under a steady current of the average velocity of the undertow, may be carried out inch by inch to a considerable depth. Thus it is that while the average velocity of currents along the Lake Michigan shore would permit them to carry sand no farther out than to a depth of about 36 feet, gravel, which may be suspected to have been carried out by the lake

currents, is found much farther off shore. It is also to be expected, of course, that irregularity of the lake shore will lead to local concentrations of the outgoing current.

The office of the undertow is primarily to dispose of material eroded by the waves; but it also scours the submerged platform across which the waves are sawing back into the land. Without it, of course, there could be no inland recession of a shore.

Shore Current—Usually the storm wind does not blow straight onshore, but at an angle to it. Consequently the waves far off shore are advancing with fronts oblique to the shore line. That part of the incoming wave which first reaches shallow water will be retarded, the wave front being bent or refracted until, by the time the wave breaks, it is nearly parallel to the beach. So efficient is this refraction that with winds from very diverse quarters the obliquity of the surf to the shore line is always a small angle. It is usually enough, however, to determine a marked drift along the shore, called the "shore current." This is the great agent of transportation of sand and gravel along shore, though it is aided in this work by the waves themselves in the zigzag swash and return flow along the beach. Although on some coasts it is true that storm winds from different quarters frequently reverse the direction of the shore current, it nearly always happens that on account of the prevailingly greater strength of wind from one direction, one of the opposed currents is the dominant one.

Development of Coastal Topography.

When a lake is first formed in an enclosed basin, or when a considerable change in level brings a lake into a new position against the land, the waves and currents find a coast which is not adjusted to their erosive and constructive activity.

The coast may be very irregular in outline and ill adapted to an organized system of waves and currents. This is particularly the case with a newly formed lake, or with a shore which has been produced by the submergence of a river-sculptured land surface (as by a sinking of the land with reference to the sea). On the other hand, if the shore line be determined by a rise of the submerged sea floor to form a shelving coastal plain, or if the lowering of the level of a lake lays bare a smooth lake plain, the shore may have a simple outline, but its profile may not be adjusted to the waves. Whatever be the nature of the initial shore line, whether it be an irregular shore of depressions or a straight shore of elevation, changes in profile, and to a greater or lesser degree in horizontal configuration are sure to be wrought out by the waves.

CHANGES IN PROFILE.

In profile, the new shore may be steep, and the undertow may thus be favored, so that more loose material will be swept off-shore by the waves than can be brought in by on-shore action. Or the slope of the new shore may be gentle, in which case incoming waves will be stronger than the undertow, and more material brought in than is swept out. In either case, the opposed forces will tend to con-

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Fig. A. Receding cliff at Gross Point.

Fig. B. Sand dunes at Rogers Park.

struct a profile on which the incoming and the outgoing of beach gravel and sand is balanced—an ideal adjusted curve known as the "profile of equilibrium." Once gained, this profile is in a general way stable. Yet it is subject to a gradual change because the beach material is constantly being worn out and scattered far off shore, and because, with progressive change in horizontal outline of the shore, the amount of waste material along shore is continually changing.

The latter element of change, the variation in direction and rate of "long-shore drift" (beach gravel and sand), is a consequence of the initial irregularity of the shore, both in plan and in profile. Not only will the shore agents seek to establish a balanced profile, but the shore currents especially will so distribute the beach waste as to reduce the irregularities of the shore by cutting back the headlands and filling in the bays. A closer inspection of this development of shore topography may now be made. It will be convenient to consider first the changes wrought in profile and then the changes in horizontal configuration, although these must always go on at the same time.

The Sea Cliff—If the initial slope is steeper than the profile of equilibrium, the waves strike the shore forcibly and cut away the material at the waters' edge, while, together with the shore currents and the undertow, they separate and carry away the debris—the coarser part being drifted along shore and the finer being carried in suspension far off shore, until it settles in deep water. The debris thus gathered is used by the waves as a tool by which to cut away the base of the cliffs. The process is essentially a horizontal sawing at the water's edge, whereby a submerged terrace, flatter than the initial slope, is cut backward into the land, and the coast above lake level is steepened to a line of cliffs.

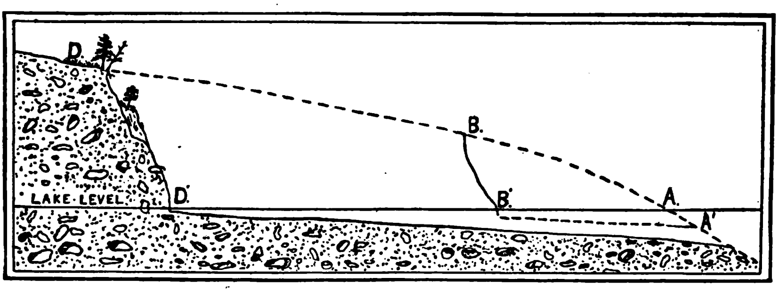

FIG. 19. Section showing how a cliff and wave-cut terrace is developed. (Salisbury and Alden.)

The initial profile D B A is thus gradually changed to a profile D D′ A′. The wave cut D′ A′, instead of being horizontal, will slope gently off shore, because its outer border began to be eroded first and because the wave action is stronger there. The width and the slope of the cut terrace, the depth of its submerged outer border, and the height of its upper border above lake level, vary according to the

strength of the wave action, the time during which the waves and currents have been at work, and the strength of material. The longer the process goes on, the broader and deeper will be the outer border of the terrace. The greater the "fetch" of the waves, the farther up the slope can erosion extend, and the higher the upper border of the terrace will be. On abrupt rocky shores the terraces are usually narrow and steeply inclined. In the north shore district, between Evanston and Waukegan, the platform at the base of the clay bluffs has a gentle slope and rises usually three or four feet above lake level. (See Plate III, Fig. A, and Plate IV, Fig. A.)

The recession of these clay bluffs is accompanied by land slips of considerable size, particularly in the spring, when the thawing of the frozen clays and the percolation of water supplied by spring rains lubricates the structure, so that great blocks of the over-steepened cliff part and slide downward toward the lake. Fresh land slides of this kind often form a sod-covered terrace or group of step-like terraces along the bluffs, the bare clay surface above the terrace frequently showing grooves where stones or roots of the loosened block scraped against the opposite side of the slipping plane during the displacement. Frequently, also, the loosened and lubricated clay slides down the cliff face in a plastic condition, forming steep cones of sticky mud; but wave action soon trims them away, steepening the lower part of the cliff, eating back into the more solid landslide block, and thus favoring a renewal of the slipping. Successive blocks are thus pulled down by gravity as the waves cut inland. Much material also creeps down the steep cliff face in small amounts, and very much is washed down by rain, developing innumerable gullies from which the waste is spread out on the beach in fan-like deposits. (See Plate XI.)

It must not be thought, however, that the shore terrace is wholly a wave-cut form. It is commonly covered with a sheet of gravel and sand called the beach, and if it borders deep water, its outer margin is usually extended by deposits of waste carried out by the undertow.

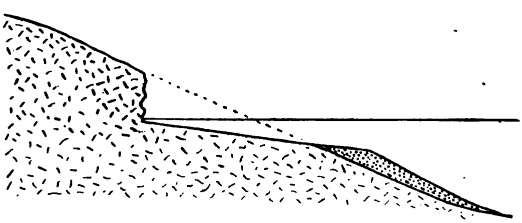

FIG. 20. Cross section of a sea cliff with a cut-and-built terrace.

So long as the shore line is advancing into an upland which slopes toward the lake, as is quite generally the case along the north shore, the shore cliffs will of necessity be increasing in height. In other words, the cliff face, from which waste is being swept to the lake by land slides, creeping, and rain-wash, is constantly increasing in area, and thus the rate of supply of waste is increasing. A critical point

Fig. A Cliff and beach near Fort Sheridan. [Courtesy of C. & N. W. Ry.]

Fig. B. Lake cliff at Racine, Wis., near Racine College. The waves have continued to encroach upon the land in spite of the piers. [Courtesy of C. & N. W. Ry.]

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may thus be reached when the supply of waste begins to exceed the capacity of the waves and currents to transport it. The waves and currents then become overloaded, the beach on the terrace is broadened and thickened by deposition of waste, and the cliffs retreat with less and less rapidity. Meanwhile, the terrace has been broadened and deepened until its outer edge may be as low as the level of effective erosion by waves and currents, a limit known as "wave base." Farther retreat of the cliffs will go on only so fast as the material of the beach is worn out by the slow grinding process, and the terrace will become flatter as more and more of it is reduced to the wave base. So it comes about that the most rapid retreat of the lake cliff is usually in the early stages of its development. It may then possess a simple wave-cut platform from which the material is carried as fast as it is fed down the cliffs. Such bare clay platforms may be seen occasionally along the north shore where cliff recession is most active, but usually the platform is covered with at least a thin veneer of sand and gravel. At those points where the till includes more bowlders and pebbles than usual, the beach is more gravelly than where the till consists almost entirely of clay. The beach reflects somewhat imperfectly the composition of the associated cliffs.

The Beach Ridge—When the coastal slope is flatter than the profile of equilibrium, the undertow is weaker than the on-shore movement of translatory waves; hence material is shifted shoreward and cast up at or near the water's edge in such a way as to steepen the slope. The profile of typical beach has a gentle sigmoid curve, the back-slope of

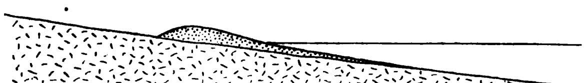

FIG. 21. Cross section of a beach.

the ridge being short, steep and convex upward, while the front slope (below the convex curve of the ridge) is long, gentle and concave—the concavity expressing an equilibrium between the opposed forces. Because the on-shore wave action increases rapidly toward the water's edge to the detriment of the undertow, the deposition becomes rapidly greater near that line and the resulting slope is increasingly steeper—that is, concave. But the crest of the ridge and its back-slope are determined chiefly by the angle at which the beach material comes to rest when cast up out of reach of the waves.

It must not be thought, however, that slope is the only factor which determines whether waves and currents of a given strength will build a beach or cut a terrace and cliff. Load (amount of sand, gravel, etc. handled by the waves) is quite important. And, as will be brought out later, the amount of load depends largely upon the strength of shore currents. Much more waste may be brought to a given place by drift of material along the shore than by the on-shore sweep of translatory

waves. Beach ridges may therefore accumulate, even on moderately steep slopes, if the supply of shore drift is too great for the undertow to sweep away.

Beach ridges are common along the abandoned shorelines of the Evanston-Waukegan district, to be described in pages 54-68. Some of them were doubteless true beaches, built by on-shore transportation in shallow water; but the more conspicuous ridges seem to have been great barriers or bars of the sort presently to be described and to be attributed mainly to long shore transportation. Occasional secondary ridges often with faint crests, which lie on the lakeward slope of the main ridges (e. g. the lower ridges on the campus at Northwestern University) seem to have been normal shallow water beaches.

The Barrier—When the initial slope is excessively flat the incoming waves break some distance off-shore and there grows up along the breaker line a reef or "barrier." The material accumulated in it is brought partly from off-shore by the incoming surf and partly from the land by the outgoing undertow. The barrier, then, like the ordinary beach ridge may be looked upon as the result of the effort of the predominant on-shore movement to steepen the slope to the curve of equilibrium, it being necessary in this case that the beach ridge be built off-shore instead of at the water's edge, if a curve of sufficient steepness is to be constructed within the range of the waves. Again, however, the long-shore supply of waste must be considered, as well as on and off-shore movements of beach material. It is believed that shore drift currents are often of great importance in the accumulation of barriers, for the breaker line is a line of greatest agitation of the water, sand and gravel is constantly being danced up and down below the breakers, and the shore currents, which would be powerless to move such coarse material if it were at rest on the lake bottom, can shift it very considerably by repeated jerks while it is temporarily in suspension. In the protected water lagoon behind the barrier, sediment swept from the land by storms or from the lake by currents may be deposited. Vegetation is likely to gain possession of this lagoon and slowly to convert it into a marsh or peat bog (Fig. 22).

So long as the supply of material to a beach or a barrier is constant, its form will be maintained in spite of the loss of material by attrition and by off-shore transportation. It may be that the supply by shore drift on the outer side will exceed the loss, in which case the reef will build slowly forward into the lake. More frequently, however, the supply fails to keep pace with the loss, especially where sand is blown inland from the beach by strong on-shore winds, forming a line of marching dunes, which are followed consistently by the beach or barrier itself. So it happens, sooner or later, that a barrier is beaten back across its lagoon, in which it is likely that considerable swamp deposits have already been formed (see Fig. 22). The line of reefs, reaching the main land shore is then replaced by the beach ridge, and finally, if erosion continues to predominate, by a line of receding cliffs.

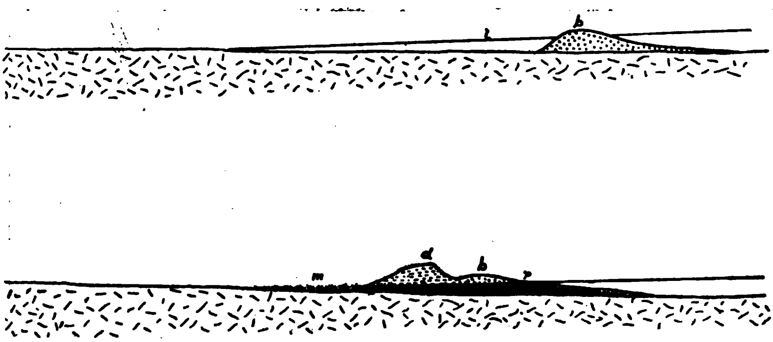

FIG. 22. Cross sections of a barrier. In the lower figure the barrier has moved inland, part way across a marshy lagoon. (b) barrier; (l) lagoon; (m) marsh; (p) peat; (d) dune.

The life history of a barrier beach is finely illustrated on the New Jersey coast. (See Figure 23.) The heavy surf of the Atlantic ocean running ashore on the low shelving coast has cast up a long line of barrier breaches a few miles off shore. At Atlantic City the barrier is a mile broad and constantly growing on its seaward side, under the excessive supply of shore drift. Hotels along the beach have been moved forward at times in order to keep near the ocean front. Farther north, near Barnegat Bay, the barrier has retreated. Here the supply of shore drift is not sufficient to counterbalance the waste lost by attrition, by off-shore scattering and by the construction and maintenance of dunes, which are marching inland across the salt marshes of the broad lagoon. On the outer side of the beach each storm exposes and gnaws back the edge of a stratum of tide-marsh deposit, a compact mass of mud and eel-grass—the former lagoon deposits across which the beach is being pushed. The lagoon narrows northward, toward Point Pleasant, where the barrier joins the low mainland. Thence northward for about 15 miles to Long Branch, the barrier is replaced by a line of low sea-cliffs which are receding so rapidly during storms as to seriously endanger property along the shore. Erosion here is in excess of deposition; the barrier has been beaten inland, worn out and replaced with bluffs.

The ultimate form of any shoreline, therefore, is normally the cliff and terrace. If the water is deep, cliffs develop at once, and are maintained so long as no abnormal supply of load is brought by shore-drift currents. If the water is shallow, a beach or a barrier is first thrown up to establish the profile of equilibrium; but if no excessive load is brought by 'long-shore currents, the barrier is gradually beaten inland and replaced by the sea-cliff.

Among the abandoned shore lines of the Evanston district, the great ridges of the Glenwood, Calumet and Toleston stages, described in pages 54-66, may be regarded as barriers, built far off-shore, partly by the on-shore sweeping of waste and partly by 'long-shore currents. The great Ridge avenue bar in Evanston is as good an illustration as any. (See pp. 61-63 and the map, Plate VI.) The absence of barrier

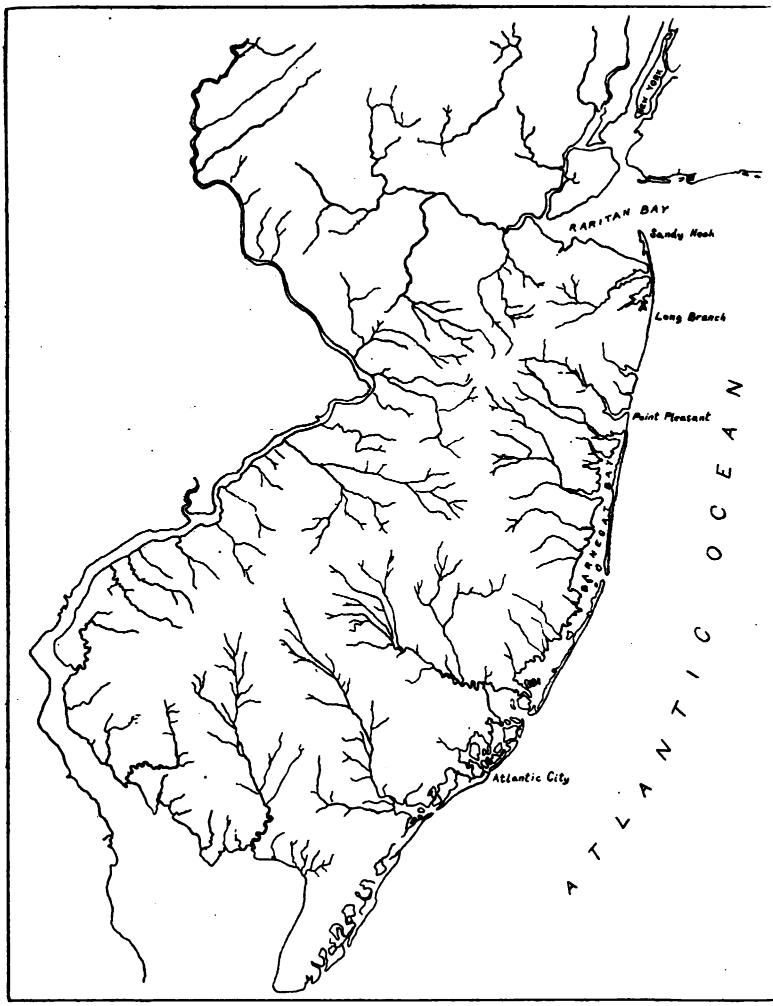

FIG. 23. Outline map of New Jersey showing the shore line with its retreating barriers.

beaches along the present shore of Lake Michigan may be attributed to the mature condition reached by the lake in the long interval since its higher stages. The present lake cliffs are comparable in their development to those of the Long Branch district.

CHANGES IN HORIZONTAL CONFIGURATION.

Spits, Bars and Hooks—The changes wrought in the horizontal configuration of the shore are closely associated with the activity of 'longshore currents, but they cannot be separated from the work of waves and undertow. It is usually true that along an initially irregular shore the headlands present steeper slopes than the re-entrants. Moreover,

Fig. A. Pier and beach near county line showing effect of southward drift.

Fig. B. Bar at mouth of ravine near county line.

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the exposure to wave action is greater on the headlands; hence the usual development of the eroded sea-cliff on the salients, and of the beach ridge or the barrier in the re-entrants of the coast.

The wasting headlands supply beach material for the shore currents to drift into the re-entrants, where it may be cast up as a "pocket- or bay-head beach," similar to the beach formerly accounted for by excessive on-shore action. With a constant excess of supply of shore-drift, such a beach will grow continually on its outer border. If it is built up across the mouth of a stream, it may form either a continuous bar, which, except during floods, is increased by the waves (a condition illustrated by Plate V, Fig. B) or a discontinuous bar, through which a channel is maintained by the stream, is formed (the case of Pettibone Creek and others of its size, Plate XII). The outlet beach is always at the farther end of the bar as viewed in the direction of the shore-drift current, because the stream is diverted to leeward by the drift. If the beach grows outward by continual deposition on its seaward side, the stream is correspondingly extended, not straight out to the lake, but obliquely, indicating a constant response to the deflective force of the shore-current. Thus in the map (Fig. 24) streams of the Long Island shore have been extended across the growing sand beaches in deflected courses (e. g. the stream behind West Meadow beach).

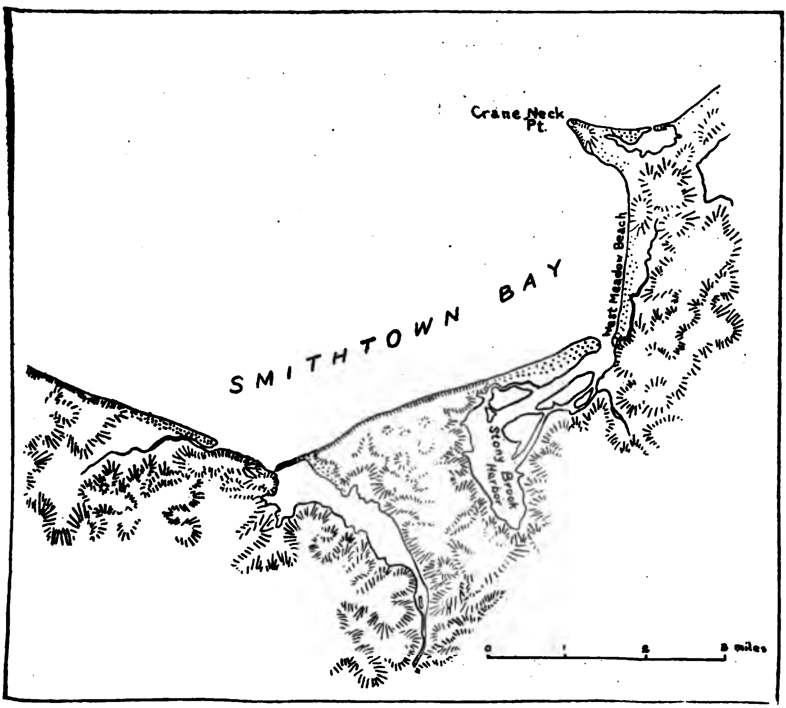


FIG. 24. Map of a part of the north shore of Long Island (sketched from the Islip, N. Y., sheet of the U. S. Geol. Surv.)

Sooner or later the deflected stream, especially if it be a small one, is likely to be blocked at its mouth by thegrowthof the terroce. Its water then reaches sea or the lake by percolation through the terrace gravels.

North of Waukegan many streams follow deflected courses behind the beach ridges of the extinct lake stages. As the lake has fallen in level, from stage to stage, these streams have incised themselves along the deflected courses, excavating valleys which run parallel to the shorelines for long distances. Deflected courses are rare and fragmentary along the present shore, however, because of the absence of spits and bars of any considerable length; but the position of the mouths of such streams as Pettibone Creek and Little Dead River, near the south end of the obstructing bars, indicates the deflecting tendency of the southerly drift currents.

It is obvious that shore currents collecting waste from the eroded headlands and moving along in a wind-driven course will fail to conform in detail to any considerable irregularity of the shore, but will extend off in a gentle curve, thus directing the shoredrift out into deeper water, where it comes to rest as a submerged reef.

The greatest deposition is of course nearest the source of supply, much of the coarser material being dropped close to the headland, while the finer is swept farther on before it comes to rest at the end of the reef. As the train of waste is built outward, it is also built up by the overloaded waves (along the line of storm breakers as already described for the barrier) and thus becomes a "spit," whose profile is like that of the barrier beach, described on pages 36-37. By continued growth, the spit becomes a "bar," reaching so far across the bay as nearly or wholly to enclose it (e. g. Stony Brook Harbor, in Fig. 24). No hard and fast distinction can be made between a spit and a bar; they are different stages of development of a single form. Nor can a bar be distinguished wholly from a barrier, for in neither of these forms is the constructive agent a single and independent one. It is convenient, however, to think of the barrier as constructed chiefly by

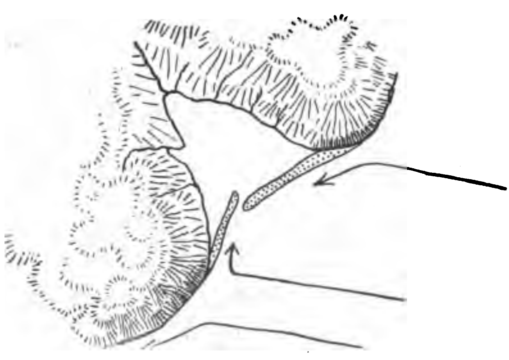


FIG. 25. Sketch map showing a bay enclosed by a pair of overlapping bars. The arrows indicate the direction of wind driven currents.

on-shore action and the bar by 'long-shore drift. Since headlands split the wind-driven currents so that on the two sides of the bay the shore-drift moves in converging or even in opposed directions, it commonly

happens that spits are built out toward each other, and the bay is finally inclosed by the union of them, or, more frequently, the overlapping of one by the other. Since the strongest surf and shore currents come with wind in one quarter, and the currents on the two sides of a bay are unequal, one spit commonly experiences more rapid growth than the other. From the greater exposure of the spit on the windward shore of the bay, it tends to hug the shore more closely than its neighbor; consequently when the two overlap the windward spit or bar is always the outer one.

The free end of a growing spit is always subject to deflection during storms when the wind comes from a quarter other than the prevailing one.

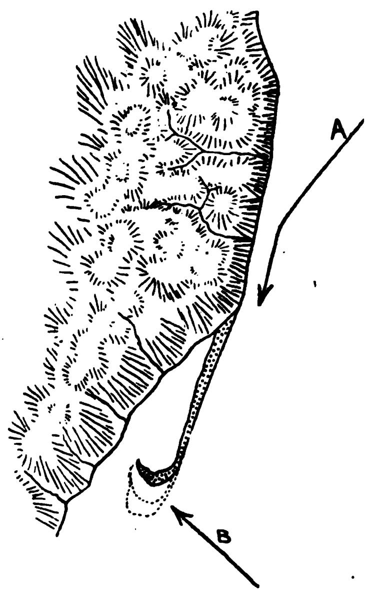


FIG. 26. Sketch map showing the development of a hooked spit.

Suppose, for instance, that the strong winds come prevailingly from the northeast; a spit will be built toward the southwest from the headland in Fig. 26 by the prevailing shore currents. If, after the spit has grown out a certain distance, it comes under the influence of a strong southeast wind (B) the shore current will be deflected in such a way that the point of the spit will be turned inward, forming a hook. With the return of ordinary conditions, the northerly shore current will be destroyed, construction of the spit will go on as at first until another change in quarter of a storm wind repeats the deflection and a new hook is formed beyond the first. A long series of hooks may thus be constructed along the growing end of the spit. This is remarkably illustrated by Rockaway Beach, near New York City (see Fig. 27).

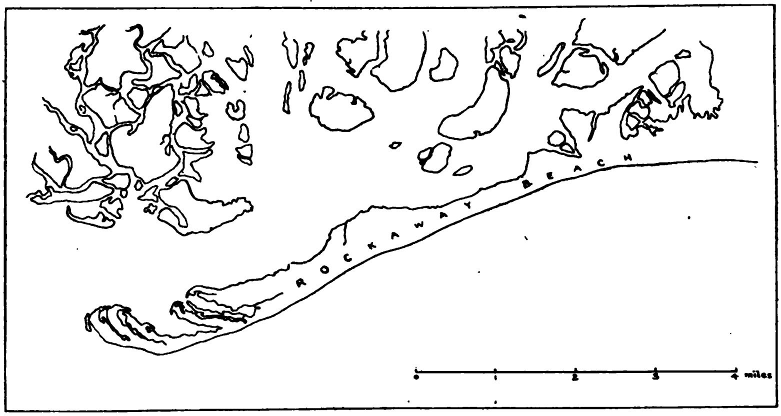


FIG. 27. Outline map of Rockaway Beach, Long Island.

Sandy Hook, outside New York Harbor, is another good example of a hooked spit, built by heavily laden shore currents, which run northward from the cliffs near Long Branch, New Jersey (Fig. 28). By continued growth on its outer side and by the shifting of dunes, it has gained a breadth of over half a mile near its northern end. Two branch spits on its western or bay side, point significantly toward the south, indicating that the shore drift on that side is a southward one, exactly opposite to the northward drift of the ocean side. This is a normal feature, to be expected on any well developd hook, as is obvious when the position of the main hook relative to the bay and the consequent fetch of the bay waves from different quarters is considered. The main spit in the case of Sandy Hook incloses a bay at its southeast corner. While a southeast storm would favor active drifting of beach material northward along the Atlantic border of the hook, it would not stir the water on the bay side except so far as the ocean waves rounded the promontory and were refracted through a large arc as they ran southward up the bay. To the extent that this occurs, the drift of material along the bay side of Sandy Hook would be southward. A southwest wind likewise would be quite as inefficient in determining the drift along the bay side, because there would be almost no fetch for the waves, and the shore under consideration would be protected from the wind by the highlands of Navesink. A west or northwest wind, on the other hand, would have the advantage of blowing the length of the bay and would clearly produce the dominant short drift—one toward the south. From the very conditions under which great hooked spits are constructed, therefore, minor branches on their protected side, if developed at all, extend in opposite direction to the main spit.

Thus it came about in one of the extinct stages of Lake Michigan, when the lake stood about 35 feet higher than now, and the great Ridge Avenue barrier in the Evanston district enclosed a broad bay (called the "Wilmette embankment" on the map, Plate VI), that two or three branch hooks were built out on the bay side of the barrier by currents running northward—just opposite to the southward flowing currents

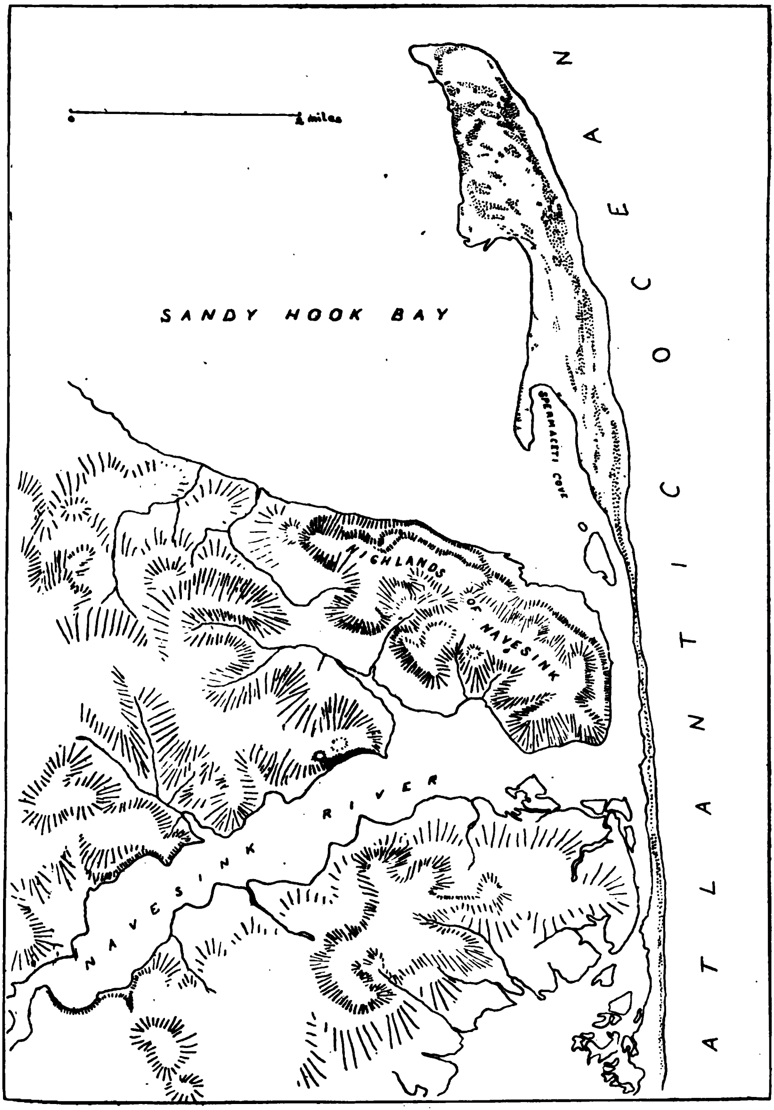


FIG. 28. Sketch map of Sandy Hook, N. J.

of the open lake. The largest of these secondary hooks lies west of Rogers' Park. Another diverges from the main ridge near the Evanston golf club grounds. These repeat, in miniature, the type of spit illustrated at Spermaceti Cave on the inner side of Sandy Hook (see Fig. 28). A comparison of Fig. 28 and Plate VI, in this detail, will be found instructive.

In the early high-level stages of Lake Michigan, described on pages 54-68, beach ridges, barriers, bars and spits were extensively developed; for the original shore of the lake, determined by glacial topography was very irregular, both in plan and in outline, and ill-adapted to wave work. Whenever the slope was deficient or the supply of 'longshore drift excessive, beach, ridges, bars and similar forms were built. But as time went on, the shores were smoothed and straightened by the waves, so as to correct the deficiencies in contour and profile, beach ridges were superseded by shore cliffs as the lake began a steady advance on the land. The present shore, therefore, exhibits no beach ridges, bars or barriers. The lake has outgrown the tendency to construct them, in its successful development of a line of mature cliffs.

DUNES.

Sand dunes, while commonly associated with shore lines, are very frequently developed independently of them. The conditions for their growth are wind, a constant supply of sand, which is sometimes dry, and the absence of a cover of vegetation. On deserts, like the Sahara, the third condition is made possible by an arid climate, while the sand is supplied by shrunken rivers and crumbling sandstone. But even in a humid climate like that of the Great Lake region, dunes may accumulate near shores where the supply of sand by shore currents is very rapid and the exposure to wind is great. In such places the wind is able to sweep the sand up from the beach faster than vegetation can establish a protective cover.

Sand is the chief constituent of beaches, for clay is extracted by waves and currents and swept far off shore in suspension, while pebbles are rapidly ground down in process of transportation along shore. The well-rounded forms of beach pebbles testify to this. Sand itself is relatively indestructible because each grain in the beach is surrounded by a thin film of water held to it by capillary attraction. When struck a blow by a breaking wave, therefore, each grain is shielded from its neighbors by a minute but efficient cushion. Without capillary attraction, sand would be far more easily worn out, beaches would be relatively rare, and the great strata of sandstone which mark long periods of earth history would be wanting. It is only when the sand on the beach dries that the wind is effective in lifting and transporting it. Periodic drying is possible along the sea border, where the ebb of the tide lays bare the beach twice every day. It is less favored on lake shores, because of relative stability of lake waters. But of course the beach cast up by a great storm becomes in part a dry sand ridge during the succeeding period of less active surf and it may then supply the sand necessary for dunes. The fact that dunes may accumulate about tideless bodies of water like the Great Lakes was expressed as an unexpected discovery by Edward Desor in his report of the surface deposits about the Upper Peninsula of Michigan in 1850.*

* Report of Edward Desor to Messrs. Foster and Whitney, "Report on the Geology of the Lake Superior Land District," Part II, chapter XVI.; Senate Exec. Doc. No. 4, 1851. The writings of Desor and Whittelsey in this report are of great interest and show a remarkably clear appreciation of shore line topography.

With a strong off-shore wind, beach sand may be blown into the lake, to be again handled by the waves and currents. But with an on-shore wind the sand is swept in beyond the reach of the waves, accumulating in low mounds about any obstructions such as stones, bushes, or clumps of juniper. Thus started, the dune is sufficient cause for its own growth, for the passing sand is accumulated in the still air on its leeward side as fast as it is eroded from the windward side. It is a significant fact that dunes are much larger and much more extensively distributed on the east side of Lake Michigan than on the west, because the prevailing winds here are west winds, and the strong east winds on which the dunes of the west shore must depend for growth are prevailingly storm winds, accompanied by rain, which wets the beach and keeps the sand in place. On the east side of Lake Michigan, especially near its southern end, to which sand is eventually swept from the whole of the shore, the dry west winds have heaped up great numbers of dunes, ranging in height up to 200 feet. In Dune Park, Indiana, the dunes may be seen moving inland across a forested area, burying and killing trees, and also moving off from previously buried forests, leaving the dead trunks as mere skeletons. A famous instance of dune migration is that of the Kurische Nehrung, a long sandbar off the north coatst of Germany, where a dune ridge within historic times marched over a church, burying it for 30 years, at the end of which time it was gradually uncovered.

Dunes are limited in height by the great velocity of upper air currents, to about 200 feet. Their on-shore march is also limited by the fact that it is attended by the attrition of the sand and the scattering over a wider area.

Dunes occur in the north shore district along the beach between Waukegan and the State line, and in less notable form at other points, as will presently be described (see pp. 51-52 and Plate III, Fig. B). They are also found in association with some of the old beach ridges of Lake Chicago, notably near the "Glenwood" beaches west of Grosse Point (see Plate VI and p. 57).

THE SHORE CYCLE.

Assuming all that has been said regarding the work of shore processes under different conditions and during successive stages of continuous activity, one may best appreciate the shore lines to be studied if the changes in their form are stated in terms of an imaginary "cycle" of shore action, such as might express the history of any shore, initially irregular, which is acted upon by the waves for an unlimited period of time. It may be said at the outset that few shore lines, if any, live to see the cycle completed, for the relation of land to sea or level of the lake is never constant for so long a time.

The shore cycle begins when the body of water comes into a new position with respect to the land. This may be brought about by a rising of the land (or a lowering of the waters, the movement being a relative one, with the same result in either case) such as is now in progress about Hudson's Bay and in many other parts of the world.

The resulting shore line is known as a "shoreline of elevation," and is characterized by long gentle curves, because it is determined by the smooth floor of the formerly submerged area. The coast of New Jersey, briefly described on pages 37-38, may be taken as a type.

The new shore line may be formed, on the other hand, by a sinking of the land with respect to the sea. In this case the waters encroach on the coast and the rough stream-carved topography is partly submerged, producing an irregular "shoreline of depression," of which the Chesapeake Bay region is a conspicuous example.

In the case of Lake Michigan, the shore cycle began when the great ice-sheet melted off from the region, leaving a lake surrounded by irregular glacial topography. Its irregular border was comparable to a shore line of depression in so far as it was undeveloped and unadjusted to the shore agent.

At the outset, the salients and re-entrants of the irregular coast, with their different exposures to wave action, experience unlike alteration. On the steeply sloping exposed headlands, the waves cut back cliffs and terraces, while the shore currents shift much debris along to the nearby re-entrants. In the more gently sloping and less exposed bays, the waves steepen the slope by casting up beaches or barriers, while the material swept in from the headlands considerably augments the load and the tendency to deposition. In the less pronounced bays, pocket beaches may result, while the sharper re-entrants will gradually be cut off by spits, bars and hooks. So long as the cliffed headlands continue to project from the shore and to supply beach material, the re-entrants will continue to fill up and build outward. Thus with receding head-lands and advancing bay shores there is a two-fold tendency to straighten the shore from one of irregular outline to one of gentle curves. In the development of these curves, the waves and currents will be guided chiefly by the initial contour of the coast and the variability of its profile, as well as by the dominant winds. The higher headlands will usually recede much less rapidly than the lower; the broader and deeper re-entrants will usually be the last to be closed by bars; the smaller headlands and re-entrants are the first to be replaced by the curve of the mature shore, but gradually the shore line becomes an organized whole, in which all parts show well balanced adjustment to the forces at work, and straight lines and gentle curves are the rule. With continued progress of the shore cycle, a mature shore may be imagined slowly to retreat as the material along its border is lost by attrition, scattering, and dune action. The barriers and bars beaten inland are succeeded by cliffs, so that the entire straightened shore consists of wave-cut bluffs.

The same progression of changes in shore line topography can be traced in a shoreline of elevation, like that of New Jersey, the chief difference being that the elevated shore line begins with a straightness comparable to the sub-mature or mature stage of a shore line of depression.

The great barrier ridges and brooks of the extinct Lake Chicago (the ancestor of Lake Michigan) mark a considerable progress of the shore cycle; for by them the initially irregular shore line was greatly

straightened. In the first, highest stage (called the "Glenwood") as shown on the map (Plate VI). Skokie Bay was nearly shut off from the main lake by the growth of a great hooked bar from Grosse Point village southward to Morton Grove. Before the shore line of this Glenwood stage had become thoroughly mature, however, the lake fell twenty feet to the level of the second or Calumet stage, and a new cycle was begun. By the drawing down of the waters across the smoothed Glenwood lake floor to the lower level, a "shore line of elevation" was produced, the straightness of the final Glenwood beach being in part inherited by its successor. Thus after each fall of lake level the process of straightening of the shore line was resumed, and each shore line of elevation was more nearly mature than its predecessor.

In a general way, the present cliffs of the north shore express the continually renewed progress of the shore cycle, in successive steps, to a stage somewhat beyond maturity. But in reality the cycle has been interrupted in other ways than by repeated lowerings of lake level. As will be told further on, there was a stage in the latter part of the lake history when the level of the waters was much lower than now, and this was succeeded by a rising of the lake upon its shores to a height of about 15 feet above the present level.

During this period of rising waters came the greatest advance in cliff development. The constant deepening of the water favored shore erosion, and the lake rapidly advanced into the land, cutting back a long line of cliffs, which are still well preserved north of Waukegan. Since this time the lowering of lake level has been resumed, and the attendant shallowing of the water on the shore has been unfavorable to the maintenance of the cliffs. North of Waukegan a broad sand terrace has been built out, but south of Waukegan the lake has succeeded better in trimming back the shore and the cliffs have not only been maintained but constantly freshened by encroachment.

Inasmuch as erosion by stream action is normally going on all the while that the shore cycle is progression there will always be gaps in the cliffs where a stream valley issues on the shore; and there a bar will be maintained by the shore drift. An exception to this rule of interaction of the shore cycle and the river cycle is found on the coast of Normandy, where the recession of the cliffs is so fast that streams by erosion can not at their mouths come to sea level, but are left well up or "hanging" on the face of the cliffs. It is rare that the shore cycle proceeds so much more rapidly than the river cycle. All the streams entering Lake Michigan within our area have lowered their valleys as fast as the shore bluffs have receded.

THE NORTH SHORE.

General Aspects—The present shore line of this region may, for convenience, be divided into three parts according to its position with reference to the old shore lines of the lake; (1) the section from Rogers' Park to Winnetka; (2) that from Winnetka to Waukegan; (3) and that from Waukegan to the State line. Along the second or middle stretch of coast line, the lake has cut back beyond its earlier shores.

North and south of it the ancient beach ridges, terraces and dunes lie inland from the present lake, but are steadily being approached and destroyed by the waves. Along the whole coast, except possibly for a few miles north of Waukegan, the present shore line is being cut back, and in most places so rapidly as to call for vigorous measures for protection of property by break-waters, piers, etc. Data collected before 1870, by Dr. Edmund Andrews, include a record of the erosion at nine points along the shore within our area:

At Evanston the erosion was 16.95 feet a year; at the old pier, two miles farther north, 0.00 feet a year; at the State line, 16.50 feet a year. Winnetka, 4.05 feet a year; one mile farther north, 6.05 feet a year; at Lake Forest, 1.65 feet a year; at Waukegan, 0.00 feet a year; two miles farther north, 0.00 feet a year; at the State line, 16.50 feet a year.

Since that time the building of piers along the whole shore as far north as Waukegan has greatly retarded, though it has not stopped the recession of the shore. From Evanston to Waukegan there is a continuous line of clay bluffs. South of Evanston and north of Waukegan, where the low sand terrace of the former lake shore remains, the present beach is low, and the indications of its recession are less conspicuous. South of Hyde Park, Illinois, and in Indiana, the shore is being built out by an excessive supply of shore drift.

Lake Survey chart No. 4 (Lake Michigan) shows that the lake floor within the five fathom line, usually half a mile to a mile off shore, is either sandy or stony, sand being more common between the State line and Lake Bluff, and a stony bottom more common farther south as far as Rogers' Park. At one place only do soundings reveal a rock bottom—a mile off Grosse Point, north of Evanston, where a protective ledge, in four to five fathoms of water, and within a mile of shore, seems to determine the most prominent salient of the shore line. Beyond the five-fathom line, the lake shore is commonly of clay in the southern part of the area and of sand in the northern part.

The Ten-Fathom Terrace—The slope of the lake floor between Rogers' Park and Waukegan is moderately uniform, though somewhat steeper outside the ten-fathom line than within it. Off Waukegan this change of slope begins to be more pronounced, and a few miles farther north, off Zion City, it becomes so abrupt as to mark a distinct terrace, whose outer border descends rapidly from the ten-fathom line, while within that line the terrace rises gently up to the shore line, with a breadth of about two miles.

In his early paper, of 1870,* Dr. Andrews called particular attention to submerged terraces shown by soundings about the borders of Lake Superior, Michigan and Huron. These were said to extend out to a depth of ten fathoms. He considered the terrace to be the "terrace of erosion" formed during the advance of the present lake into the land, it being remarked that "the waves of our great lakes ceased to have any erosive power upon the bottom at the depth of about 60 feet; hence, when the shores are worn back there is left under water a sort of shelf or terrace, the surface of which slopes gently outward

* "The North American lakes considered as chronometers of post-glacial time." Chi. Acad. Sci., Trans., Vol. II, pp. 1-23.

to the depth of about 60 feet. * * * * * * Where the shores are of drift clay the terrace generally has a breadth of from two to six miles, and occasionally more. But where it is of rock the width is much less. On some of the hard rocks of Lake Superior the terrace is scarcely 200 feet wide. Softer rocks frequently show a breadth of 1,500 feet. It is a curious and unexpected fact that the depth of the erosion is much less affected than the breadth of it by the hardness of the material. Even rock shores often show the edge of the terrace to be 60 feet down."

Andrews' explanation of the terrace finds another contradiction in his statement that "the waves cease to have power to move sand at the depth of twenty-four to thirty-six feet. * * * Beyond thirty-six feet depth the bottom [of the southern part of Lake Michigan] is always of a smooth impalpable clay."

When it is realized that a considerable part of the material in the receding cliffs of bowder clay is pebbles and sand, it is hard to see how a terrace could be cut in this material to a depth of 60 feet by waves which fail to move sand in water deeper than 36 feet. Moreover, we might well expect to find the terrace strongly developed offshore from the present clay bluffs of the Evanston-Waukegan district if anywhere; whereas there is only a long or rather gradual slope.

All these inconsistencies suggest that the terrace may be better explained in some other way than by the activity of Lake Michigan at its present level. It will be stated in succeeding pages that during the latter part of the early stages of the lake, the waters in the Michigan, Superior and Huron basins were all drawn down, at least 50 or 75 feet below their present level, by the opening of a new and lower outlet beneath the retreating ice sheet near North Bay, Ontario. (See Fig. 35.) The borders of the lake basin were then laid bare even more extensively than now. By a differential uplift of the northeastern part of the Great Lake region, which did not directly affect the southern part, this North Bay outlet was raised higher and higher, while the lakes everywhere in the southern parts of the basins responded by rising upon their shores, submerging them to a greater and greater extent, until they finally overflowed at Port Huron (the southern end of Lake Huron), and further drowning of shores was rendered impossible by the southern outlet. It seems probable that this ten-fathom terrace marks the erosion of the lake border, while the waters were rising from the low North Bay plane, to essentially their present level,—a time peculiarly favorable to the cutting back of a long line of cliffs and a broad terrace; for constant deepening of the water means constant steepening of the submerged slope and increase in the capacity of the waves and currents to erode and transport material.

So as the waters rose and the lake cliff was cut back, a broad, gently sloping terrace of erosion might be worked out, the outer border of which would be much too deep for the present waves and currents to erode, but at the depth appropriate to a terrace cut during the North Bay stage. According to this explanation we would be led to suppose that the North Bay plane of the lake was about 60 feet lower than the

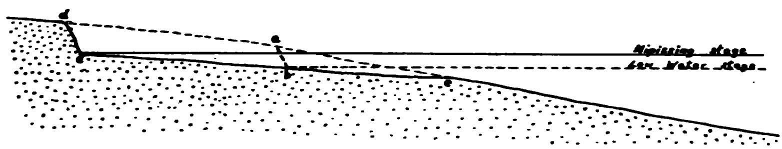


FIG. 29. Diagram showing how a deeply submerged terrace may have been developed by cliff recession during a rising of the water level from the low water stage to the "Nipissing" stage. (a b c) cliff and terrace cut during low water stage; (d e c) cliff and terrace after the rise and encroachment of waters.

present. It may be said, however, that detailed study of the lake charts prepared since Dr. Andrews' time shows that if a ten-fathom terrace does exist over a wide area it is often discontinuous and not of uniform height. Not too much emphasis should be placed upon it.*

THE COASTAL TOPOGRAPHY.

Rogers Park to Winnetka.—Near Rogers Park, the beach lies on the outer side of a broad terrace of sand ridges, beaches, and dunes which were built while the lake was falling from an old level to its present mark. The crest of the present beach rises 3 or 4 feet above the lake, and is usually well covered with "shingle," i. e., well rounded discoidal pebbles, whose shape bears witness to a long journey along the shore. The waves break moderately close to shore, showing that the profile of equilibrium is fairly well established by the beach. The conditions are in some measure artificial, however, for piers and breakwaters have been built at frequent intervals to catch the shore-drift and thus to accumulate a beach deposit more rapidly than it can be worn out and transported by the shore agents. These piers act substantially like rock headlands, affording re-entrants or artificial coves in which pocket beaches are built out in an endeavor to straighten the shore line. From the end of each a submerged sand spit runs southward parallel to the shore, in the path of the deflected shore current just as a drift-built spit tails out from a headland across a bay. It is very noticeable that the beach accumulates more rapidy on the north side of each pier than on the south side, because the dominant drift by both waves and currents is toward the south.

In spite of the piers and artificial beaches, the lake is advancing on the land at a rather rapid rate. The cutting is obvious at several places in Rogers Park where streams run out to the lake shore and the cement sidewalks or the macadam road structures end brokenly at the border of the storm beach. Recession is just as truly indicated, however, by the natural cliffs cut by the waves in the old beaches 10 to 15 feet high and in the

* Mr. Leverett states in a letter to the present writer, May 26, 1906, that after examining the charts with this matter in mind he finds frequent terrace-like stretches which suggest that a submerged shore line rises slowly from twelve fathoms near Chicago to ten fathoms at Milwaukee and eight fathoms or less in the northern part of Lake Michigan, as if from tilting. But he does not regard the evidence as of much weight.

dune ridges. These dunes are forested, and have been established in position for a very long time, but are now being slowly destroyed as the waves cut inland. The recession of the shore is accomplished, of course, only during heavy storms when the waves rise across the beach and attack the sand deposits along its inner border. After such a storm, when the water has subsided to a lower position on the beach slope, the waves build up a secondary beach profile, relatively low and weak in expression, at the water's edge.

Near the southeast corner of Calvary cemetery, in South Evanston, at the turn in Sheridan Road, is a small belt of sand dunes, which are not "established" like those of Rogers Park, but actively moving inland. They are only 15 feet high, and almost bare of vegetation, clothed with almost nothing but beach grass. The dense network of rootlets is well shown on the eroded outer side of the dunes. The contrast between the bare lake-ward slopes and the grass-covered inland slopes comes out well as one looks along the line of sand hills. (Plate III, Fig. B). A lone tree, withered and lifeless, with its trunk and spreading roots half resurrected from a cover of drift sand on one of the dunes tells the story of dune migration, like the church at Kurishe Nehrung, or the resurrected forests at Dune Park.

From Calvary northward through Evanston to the Life Saving station, beakwaters, piers and made land interfere with the normal shore line topography. On the campus of Northwestern University, the lower of the old shore lines run obliquely out to the lake, and the low-cut bluff is 20 feet high, and capped by the beach deposits of the Toleston, or 20-foot, stage of Lake Chicago (see pp. 65-66). A long pier at the Evanston waterworks has induced the accumulation of a broad protective beach at the north end of the University campus, and the bluff there is consequently established. At Grosse Point, the bluff consists of the characteristic till or bowlder clay, with hardly a foot of old lake-floor sediments above it. Where the Calumet beach ridge is cut off by the lake at Grosse Point, the bluff is 40 feet high, and shows a very good section of the till and over-lying beach deposits. The cliffs are rapidly receding at this point, and new landslides are often seen after a storm. The salient Grosse Point seems to be due in part to the protective off-shore ledges and in part to the Calumet beach ridge.

From Grosse Point to Winnetka the freshly cut bluffs maintain a height of 25 to 50 feet, running obliquely across the till plain which formed the floor of the Wilmette embayment, during the Calumet stage (see Plate VI).

Winnetka to Waukegan.—In the northern part of Winnetka the bluff (which marks the highest of the extinct lake stages) is cut off by the present shore, and farther north, for about 20 miles, the lake lies against the Highland Park morainic ridge, with steep cliffs from 50 to 100 feet high. These cliffs are actively receding, although in most places the recession is very considerably retarded by the protective piers, which obstruct the shore-drift and maintain a narrow beach. The southward drift of shore currents is clearly seen here, as elsewhere by a greater accumulation on the north side of each pier. One exceptionally long pier, which shows this well, is just north of the Cook

county line (Plate V, Fig. A.) Landslides on the cliff face, gullies, and fans, as described on pages 33 and 34, are all exhibited here. Locally, however, protection is so efficient as to allow the cliffs to become established in position and covered with young vegetation.

Across the mouth of each large ravine the waves maintain a bar of shingle and sand, usually a complete barrier to the little stream. The streams are so small and so intermittent in their activity that in ordinary times they offer no resistance to the obstructing waves. A stagnant pool of water behind the bar filters slowly through the gravels and sand as fast as it is brought down the ravine. A heavy shingle bar blocks the mouth of a creek at the Cook county line (see Plate V, Fig. B). During exceptionally heavy rains and spring thaws, however, the stream may be so swollen as to over-top the bar and to cut a channel across it in spite of the opposed wave action. The largest streams, of course, most often open a channel. Pettibone Creek is one of these, which usually carries enough water to maintain at least a small breach through the south end of its bar (see Plate XII).

Waukegan to the State Line.—At Waukegan a coastal terrace makes its appearance, and, rapidly broadening, runs northward with a width of a mile or more, across the State line. This is a fragment of the same low terrace which borders the shore south of Evanston,—a broad stretch of beach sediments corrugated by ridges which have developed along the whole shore during the recession and subsidence of the lake; but it has been destroyed by cliff recession between Waukegan and Evanston. At its southern end, in the yards of the American Steel and Wire Company, at Waukegan, this terrace has been considerably extended by artificial filling, or erosion on its borders would doubtless be as apparent as on the face of the clay bluffs immediately to the south. North of the city there is reason to believe that the shore is stationary or even building out, as suggested by Dr. Andrews' figures. The sandy beach is bordered by active dunes, which show no sign of loss on the outer side by wave erosion nor of rapid landward migration. They support a scant growth of beach grass, juniper, and scrub pine, which only imperfectly prevents the shifting of the sand. Occasionally a clump of juniper acts as a nucleus for a growing young dune, but more frequently the relation between the hills and the juniper seems to be very irregular. About the clumps of beach grass there are frequently circular markings on the sand made by the whisking about of the grass by the wind. Gravel appears not only along the beach but beneath the dunes on their outer side and about 10 feet above the lake, marking beach deposits of an extinct stage. In the dune district between Waukegan and Zion City it is not apparent whether the dunes are moving inland or not. Since the winds, especially the dry winds, are prevailngly off-shore, the dunes must lose much material by scattering into the lake. If the beach were advancing lakeward, the dune belt would probably be broader than it is, for it is only 100 yards broad at most, and toward Waukegan much narrower. Behind the dunes the broad tract of marsh, interrupted by low flattish ridges of sand and occasionally sloughs or lagoons of stagnant water, reaches inland to the sharply cut bluff of an extinct 14-foot stage. Dead River is

one of the largest of these sloughs. At Zion City, Shiloh boulevard leads eastward from the railroad station to the lake, affording a good opportunity to study the corrugated sand and marsh terrace and the beach and low dunes of the present shore. Andrews' figures show that the beach near the State line is retreating at a very rapid rate, and an inspection of the terrace ridges and sloughs (as shown on the Coast Survey chart) confirms this fact. The ridges run obliquely out to the lake, where they are successively cut off by the advancing beach.

Mature Condition of the Shore Line.—The present shore line is one of long sweeping curves, well established profile of equilibrium, and landward encroachment, having all the characteristics of maturity. That this advanced stage is due not simply to the work of the lake at its present level, but in a large measure to the smooth floor and even border which Lake Michigan inherited from its ancestors, has already been mentioned, but will be more strongly appreciated when the history of the lakes is reviewed.

THE RECORDS OF THE EXTINCT LAKES.

BY J. W. GOLDTHWAIT.

INTRODUCTION.

Lake Michigan is the lineal descendant of a series of extinct lakes whose history is recorded in raised beaches and terraces, abandoned outlets, and lake floor deposits higher than the present lake. The ancestral lakes owed their high level to the great ice sheet, which acted as a dam across the northern side of the basins, holding the water up to the level of the lowest notch in the inclosing land basins. The cutting down of outlets, the uncovering of new outlets at lower levels as the ice sheet melted northward, and differential uplifts or tiltings of the land combined to complicate the series of changes in level and outline of the lake during its early history.

The Evanston-Waukegan district contains stretches of the abandoned lake shores, in which one may read somewhat imperfectly the record of successive events of lake history. Between Winnetka and Waukegan the old shores have been totally destroyed by the advance of the lake upon the land; but north and south of this section, shore forms of considerable variety and of great instructiveness are to be seen well above the present shore.

In the Evanston district, the old lake shore is much smoother than the higher upland back of it, and forms the northern corner of the cresentiform Chicago plain. While this is a lake plain in the sense that it is the floor of an extinct lake, the plain does not owe its flatness wholly to submergence. The greater part of it is covered with bowlder clay, thinly veneered, if at all, by lake floor sediments. Had the original floor been as irregular as the upland and then been smoothed off by wave action, there would hardly be such broad stretches of the lake plain left bare of lacustrine sediment. The plain seems therefore to be a glacier-made till plain, whose surface was given a finishing touch by the lake water which once covered it. In this respect it is to be contrasted with the broad, flat plains of the Red River valley in Dakota and in Minnesota, which was once beneath a similar ice-front lake, but is flat because of the accumulation of fine sediment to a depth of 40 or 50 feet on the lake floor.

In the Waukegan district, the area once covered by the lake is by no means a plain. It includes not only a broad flat terrace along the present lake shore, but a steep, high bluff, and a sloping upland with several parallel beach ridges.

It is the purpose of the present chapter to point out and explain these records of the former higher levels of the lake. The history of Lake Michigan is closely connected with the history of the other Great Lakes. This history has been worked out chiefly by Mr. F. B. Taylor, Mr. Frank Leverett, and Dr. W. C. Alden, of the United States Geological Survey.*

LAKE CHICAGO.

Glenwood Stage.—At the time of its last great advance, the North American ice sheet reached southward as far as the lobate border indicated in Fig. 30. As its front withdrew by melting from the terminal moraine, and began to uncover the south end of the Lake Michigan basin, a body of water appeared between the ice front and the inclosing moraine,—a lake which has been appropriately named "Lake Chicago."

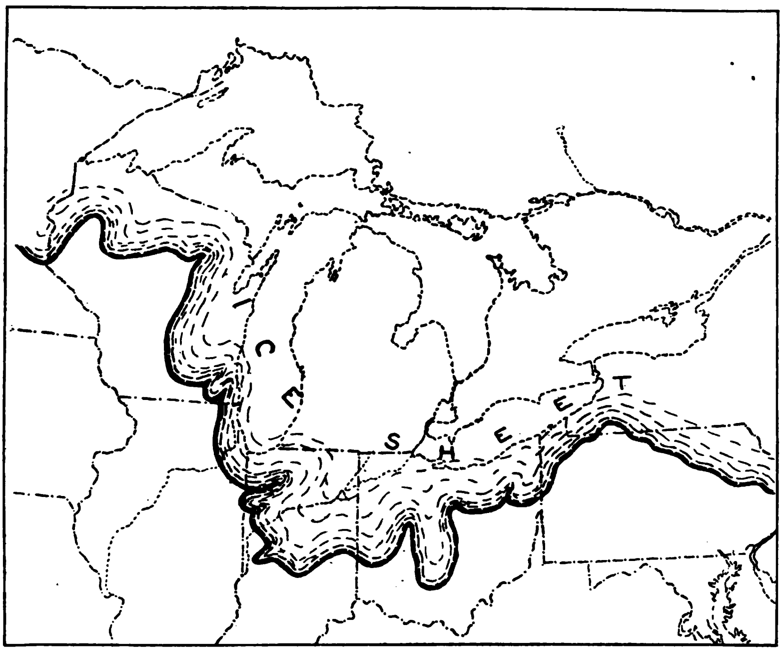


FIG. 30. Map showing the ice sheet of the late Wisconsin stage, at the time of its greatest extent.

Its outlet was through the lowset notch or "col" in the morainic divide near Chicago, along the line of the present drainage canal into the Desplaines and Illinois rivers.

When the lake first formed along the margin of the Michigan ice lobe, the outlet col seems to have been high enough to hold the waters up to about 60 feet above the present lake level; but, by rapid cutting, it

* For the correlation of the lower stages of Lake Chicago with Lake Algonquin and the Nipissing great lakes, the present writer accepts all due responsibility. This part of the lake history must not be considered as completely demonstrated.

was soon lowered a few feet, becoming stationary at about 55 feet above Lake Michigan. Possibly the halt at the 55-foot, or *Glenwood,* level was determined by the discovery of a sill of bed rock beneath the loose drift of the outlet valley.*

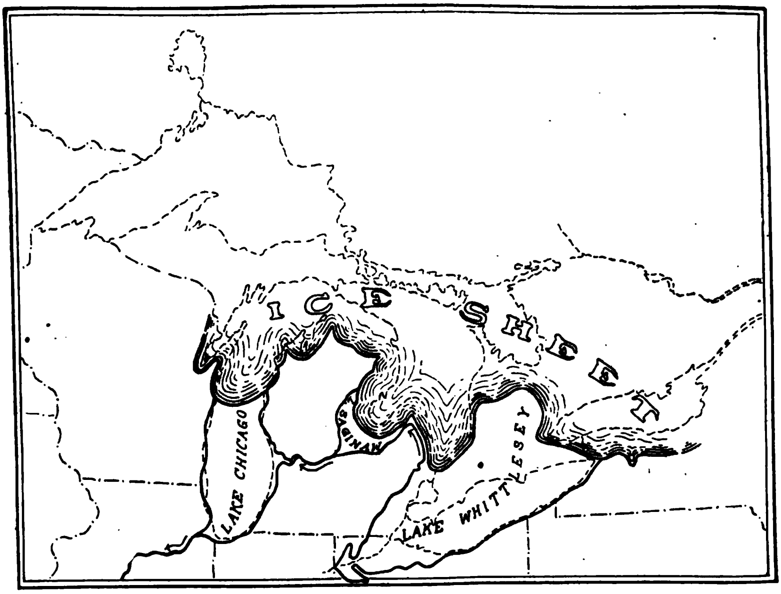


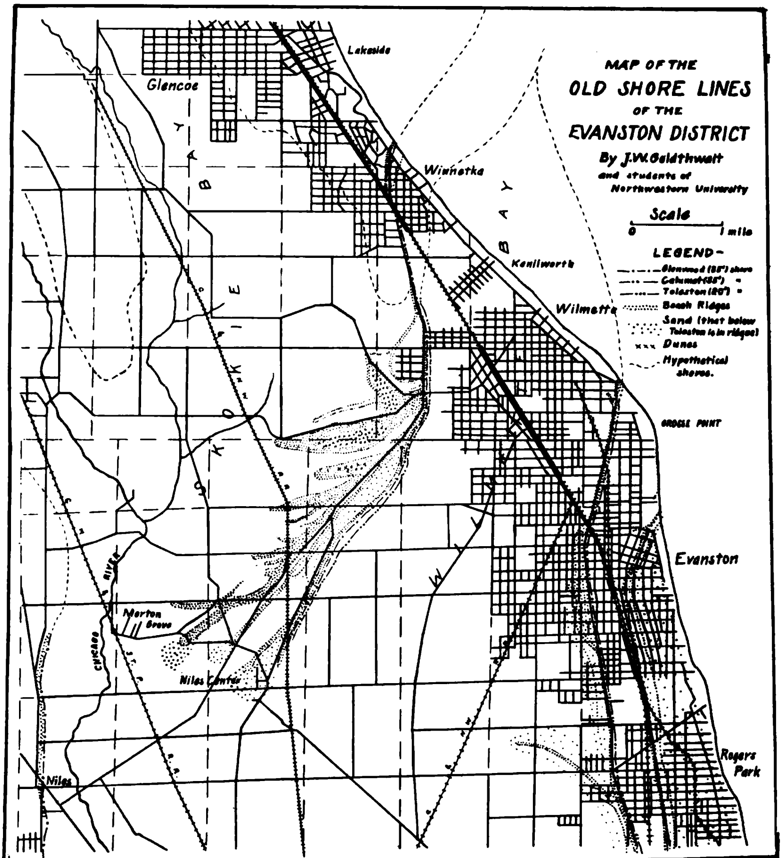
FIG. 31. Map showing the ice front lakes and the ice sheet at the time of the re-advance to the Port Huron-Manistee moraine. (Leverett and Taylor.)

At one time before the close of the Glenwood stage, the ice seems to have halted in its retreat and to have even re-advanced to the vicinity of Milwaukee, over-riding the Glenwood beach deposits there, and burying them beneath a thick deposit of ice-laid and water-laid red clay.†

Glenwood Shores in the Evanston District—In the northern part of Winnetka, a short distance south of the pumping station, the cliff and terrace of the Glenwood stage appear half way up the lake cliff, and extend inland with pronounced form for three-quarters of a mile. The terrace is about 55 feet above Lake Michigan, and is composed of stratified sand and gravel; and behind it the bluff rises to a height of 20

* Investigations by the writer in the Chicago outlet, since this report was written, make it probable that the level of Lake Chicago in the Glenwood stage was controlled not by a sill of rock, but rather by the surface of a gravel deposit (a "valley train") which occupied the valley below Lemont, when first the ice withdrew from the district. It may have taken the outlet river a long time to sink its channel through this gravel deposit, for it reached 15 miles or more down the valley.

† These are described by Alden in the Milwaukee folio, U. S. Geol. Surv. That the lake was still at the Glenwood level after this advance seems to be shown by the occurrence of beach ridges at the Glenwood level, and superposed upon the red clay in Sheboygan county, Wisconsin, 35 miles north of Milwaukee.


MAP OF THE
OLD SHORE LINES
OF THE
EVANSTON DISTRICT
By J.W. Goldthwait
and students of
Northwestern University
Scale
0
1 mile
LEGEND–
Glenwood (55') shore
Calumet (35') "
Toleston (20') "
Beach Ridges
Sand (that below Toleston is in ridges)
Dunes
Hypothetical shores.
Lakeside
Glencoe
Winnetka
Kenilworth
Wilmette
Grosse Point
Evanston
Rogers Park
Morton Grove
Niles Center
Niles
Chicago River
BAY
SKOKIE
WILLMETTE BAY

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OF
CALIFORNIA

to 30 feet, with a very steep slope, affording a fine outlook for residences facing this lake. A short distance out from the base of the bluff is a low sand ridge, which seems either to be an off-shore reef, or a beach thrown up when the lake fell slightly from the level at which it had cut the bluff. A second sand ridge lies about a block east of the first, running out to the brink of the lake cliff, as shown on the map (Plate VI).

The old cliff runs southward on the west side of Maple street, becoming less distinct as it approaches the railroad, where artificial grading has destroyed its true form. On the west side of the railroad, south of Cherry street, it appears indistinctly. Close to the east side of the Grosse Point road is a belt of gravel behind which the rolling upland of the Highland Park ground moraine ridge, which here tails out, is covered with a sheet of wind-blown sand, two to eight feet thick. Beyond the end of the moraine west of Kenilworth, the beach assumes the form of a distinct ridge, followed by the road to Grosse Point. A half mile north of Grosse Point it sends out its first hook to the southwest, a narrow ridge of gravel three-quarters of a mile long. In the southern part of the village several smaller hooks curve sharply around to the west. the outermost forming a quarter circle, followed by a curving road and connecting with the most northerly hook at the road corner northwest of the village. This outer hook is much broader than the others and is made irregular by a line of sand dunes. which are 25 feet high, but greatly subdued by plowing and rain-wash. A branch ridge runs nearly straight west from this for over half a mile. The largest hook of all, however, runs west-southwest from Grosse Point, and is followed by the Glen View road. This is a mile and a half long, and banked up with a line of subdued dunes.

About a mile south of Grosse Point the main or outer beach ridge divides, the inner ridge taking a course a few hundred feet west of the ridge road which follows the outer one. Half a mile farther on, the outer forks again, so that there are three distinct ridges, all parallel and all of approximately the same height. The outer one is bordered by a terrace which seems to be the shore line of the next lower of the stages of Lake Chicago. It is followed for a mile or two by a branch of the ridge road, and gradually spreads and flattens out at Niles Center. The middle of the ridge determines the course of the main road nearly as far as Niles Center, flattening, like the first, into a low sand deposit. The inner ridge, which is the best developed of all and a few feet higher, sends off about twelve hooks on its west side, and finally terminates east of Morton Grove, in a spreading gravel deposit.

West of the Chicago river and southwest of Morton Grove, the road to Niles and Norwood Park follows a beach ridge which marks the continuation of the Glenwood shore. In section 19 (Niles), the ridge shows only imperfectly the effects of shore action, being covered with only a thin deposit of gravel and sand; but approaching Niles it becomes a very marked ridge, with characteristic sigmoid profile and gravelly structure. Through the village of Edison the shore line is a little

obscure, forming a gravei slope against a moderately steep till bluff; but at Norwood Park (just south of the map, plate VI), it again becomes a strong-feathered ridge, whose crest, by railroad levels, is 59 feet above Lake Michigan.

The form of the complex set of hooked bars and their relation to the cut bluff and gravel beach at Winnetka, indicate that they were built by strong southward shore currents which swept around the end of the eastern moraine ridge and across the Skokie marsh, which was then a bay (Plate VI). North of Grosse Point the water was too shallow to permit the formation of any considerable hooks, the shore currents running straight southward; but south of that place, where the currents ran out into deeper water, they were subject to frequent deflection, and well marked hooks were built one after another as the bar grew, like the hooks on Rockaway Beach, Long Island (Fig. 27). So far was the hooked bar extended, that it nearly shut in the Skokie embayment, leaving a gap at Morton Grove only a mile wide. The building of the middle and outer ridges may have been initiated by a very slight fall of lake level, toward the close of the Glenwood stage. The northward weakening of the Glenwood beach from Niles toward Glenview, shows the effect of the Grosse Point bar in protecting the shores of the Skokie re-entrant.

There was doubtless an embayment also in Glenwood time in the Desplaines valley, running northward at least as far as Desplaines, but no distinct shore topography was developed in so shallow and so protected a re-entrant. It was shut off from the open lake by a great hooked split, at Oak Park.*

Glenwood Beaches in the Waukegan District—In the city of Waukegan the Glenwood beach ridge may be found just east of Genesee street, running northward on the west side of Sheridan road not far back from the top of a steep bluff that marks a much lower stage (Fig. 32). Although usually much obscured by grading, the beach ridge is in some places quite distinct and has an altitude of 50 to 55 feet above the lake. In the southern part of the town it seems to have been cut off by the advance of the lake on the land at a later time. When followed northward it is seen to cross the Kenosha highway in section 16, and to follow close to the brink of the Toleston bluff where the road runs eastward (between sections 16 and 9) to the lake. The Glenwood ridge is closely associated with rolling morainic mounds, which in places are quite sandy and may in part be covered with dune sand. In section 9 (Waukegan) the 55-foot ridge is broken in several places by transverse streams. Behind the bar a small creek, following a deflected course for a mile or more, has cut a deep, terraced valley. Curious topography produced by the encroachments of the lake on the one hand and the terracing of the deflected stream on the other, will be described in a later chapter (pages 83-84).

* See Salisbury and Alden, "The Geography of Chicago and Its Environs," Geog. Soc. Chi. Bull. 1, pp. 35 to 37.

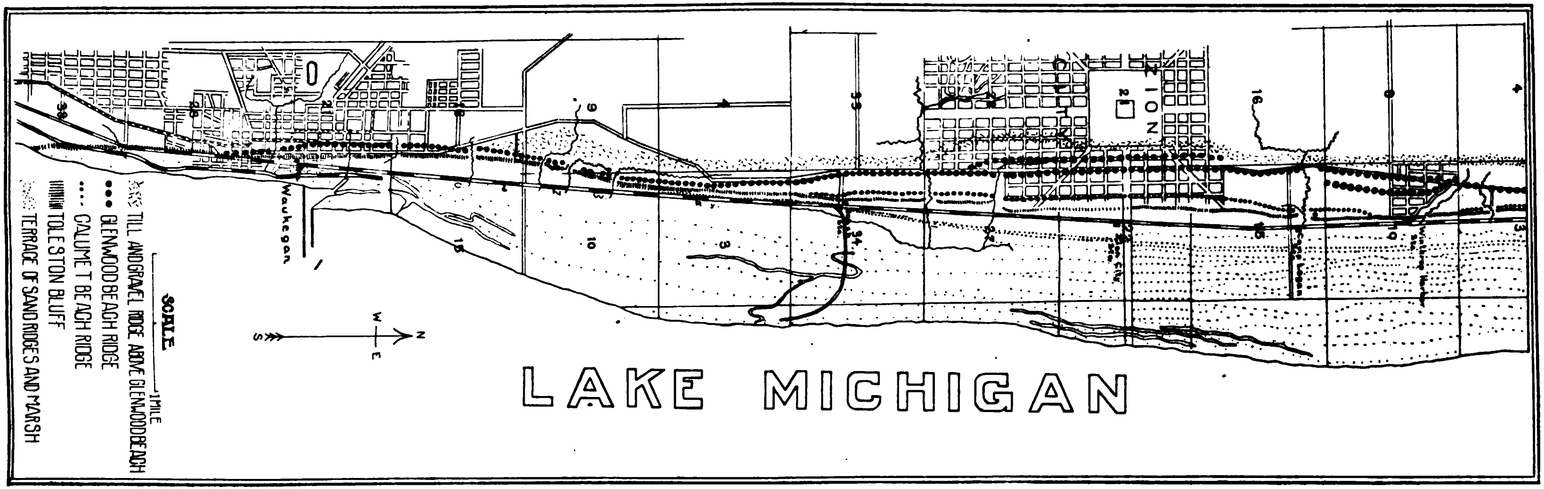

FIG. 32. Map of the old shore lines between Waukegan and the State line.

In section 4 (Waukegan) the beach ridge continues northward with characteristic strength, and thence for over six miles is followed by Sheridan road. Near Beach station it has three closely set crests. At Zion City it is double, the two ridges having the same height, 53 feet above the lake, and crossing Shiloh boulevard near Dowie's residence. In places it is raised a few feet by blown sand. Near Withrop Harbor it is again double and not so well defined. Behind it, on the outer slope of the till ridge, a low cliff has developed. The beach ridge crosses the State line with a crest which rises and falls several feet because of dune action.

West of this 50 to 55-foot Glenwood beach ridge is another long ridge, from 5 to 15 feet higher, usually much broader, and commonly so till-like in structure as to suggest an ice-front deposit rather than a beach ridge. Locally, however, (as at the gravel pit at the southeast corner of section 9, near Winthrop Harbor), it is seen to be built of well stratified gravels. As is shown by the map, this till and gravel ridge can be followed continuously from the State line nearly to Waukegan, where it blends with the rolling morainic topography.

This outermost ridge, 60 to 70 feet above Lake Michigan, might be regarded as a deposit formed near and in part against the ice front when Lake Chicago was first opening and before the erosion of the Chicago outlet had established a 50 to 55-foot mark. The lake at that time was probably only a narrow belt of water against the ice (somewhat broader, however, north of Zion City), and wave action was weak and embarrassed by ice-front accumulations.

THE CHANGE FROM THE GLENWOOD TO THE CALUMET STAGE.

While the ice front receded and Lake Chicago expanded northward, the erosion of the outlet floor seems to have been suddenly checked, and to have ceased temporarily; so as to hold the lake for a considerable time at a level about 35 feet above the present. It seems as if the drop from 55 to 35 feet was a rather sudden one, for the Glenwood and Calumet beaches are usually quite distinct, with no beaches to mark intermediate stages. Accordingly, a process of sudden deepening of an outlet, known as "stoping," has been suggested. In brief, it is as follows:*

The outlet of a lake may flow across a region of horizontally bedded rocks in which certain layers are weak and others resistant (see Fig. 33, upper diagram). Under such conditions rapids or even falls are likely to be developed where a river runs off from the hard stratum on to the weak one. While in the upper portion of the outlet, the hard layer suffers very little erosion, the rapids farther down quickly work up stream, by sapping or stoping. Thus, while the lake is held to the level of the sill at the head of the outlet, the rapids work up stream nearer and nearer the lake, and finally cut through the sill with a rush, and the lake level falls suddenly into adjustment with the flat "stope." It is not even necessary to

* This explanation is merely an abstract of Professor Chamberlin's original presentation of the view of stoping, in Monograph XXV, of the U. S. Geol. Surv., "Lake Agassiz," pp. 250-251.

postulate a bed rock structure, for, if the outlet is across a morainic ridge whose outer border is moderately steep and whose structure is locally very resistant, stoping may take place. Suppose, for instance, that in Figure 33 (lower diagram) an outlet for the lake is found across the moraine in a line of cross-section, and that at b-c there is an exceptionally resistant belt of drift, more bowldery and compact than the surrounding drift. Profiles of erosion would develop in succession somewhat as indicated in the figure, rapids forming first on the outer side of the resistant band and working up stream until they cut through the obstruction, whereat the weaker material, no longer protected, would quickly yield to erosion and the lake would fall to fit the new channel floor.

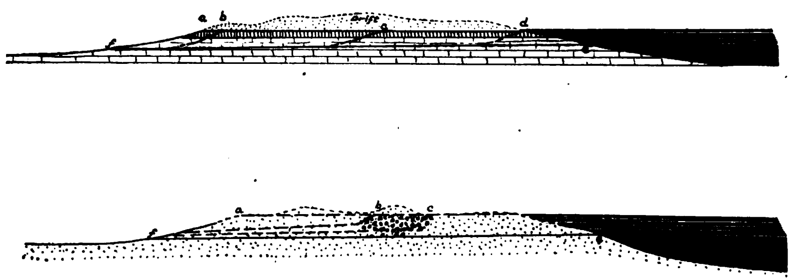

FIG. 33. Diagrams showing in profile how the level of a lake may suddenly fall by "stoping." In the upper figure the stoping is through horizontal bed rock. In the lower one it is through a resistant portion of the moraine. a, b, c, d are successive positions of the top of the rapids developed by stoping; e is the final position of the head of the outlet.

THE CALUMET STAGE.*

The lake remained at the new level, 35 feet above the present lake, for another long interval, while the ice withdrew toward the northern part of the Great Lake region. Strong beaches and terraces were formed in the Chicago district, and northward at least as far as Ludington, Michigan, and Manitowoc, Wisconsin. How much farther north they extended is not known. The Calumet stage seems to have closed with the lowering of the Chicago outlet of the lake 10 to 15 feet.†

Calumet Shores in the Evanston District.—During the Calumet stage, nearly the entire till plain east of the Glenwood beach was submerged, for it all lies below the 35-foot mark. The border of the

* It has long been supposed (following Dr. Andrews) that the Glenwood and Calumet stages were separated by a stage of low water when the lake fell to a level at least as low as the present and probably much lower. The evidence cited is a peat bed which lies beneath the Calumet ridge at Grosse Point. But recent study of this locality strongly suggests the "peat" is merely a lacustrine deposit, formed in quiet water behind the barrier during the Calumet stage, and buried by shoreward advance of the reef. Other evidences of a low lake stage, once correlated with the pre-Calumet stage, seem now to belong to much later periods, described on pages 63 and 66.

† Recently evidence has been found at Lockport which seems to indicate that this second drop in level of Lake Chicago was accomplished by stoping of the old outlet through a sill of bed rock at that place.

lake was near the outer Glenwood bar. Between Niles Center and Grosse Point, it is marked by a pretty distinct terrace of gravel, sand, and black soil, such as might be expected to form along the shore of an embayment. About three miles east of this, a great off-shore barrier was built at this stage, the Rose Hill barrier, which is followed for six miles by Ridge avenue, through Evanston and Rogers Park, and terminates near Rose Hill cemetery. This barrier, like the Glenwood bars, was doubtless constructed in part by southward shore currents, which brought gravels and sand from the cliffs east of Winnetka. But all of the ridge north of Grosse Point, and the associated cliffs, have been cut away by Lake Michigan, the Ridge avenue bar then protected a long lagoon, which we may call for convenience the Wilmette embayment, since Wilmette is near the head of the bay and on its floor. The Ridge is a conspicuous feature, and is widely known for its well-built boulevard and its fine residences. It rises about 20 feet above the flat till plain, with a steeper slope usually on the western side than on the east or front. While the whole barrier deposit shows a width of a quarter to a half of a mile, the beach ridge on its outer side is very narrow (see Plate VI).

At the termination of the ridge, near Grosse Point, a freshly exposed cross-section may usually be seen in the lake cliff, in which the brown cross-bedded beach gravels overlie horizontally bedded sand and the glacial bowlder clay. Close to the base of the stratified portion is a band of peaty clay, very thinly laminated, and composed in part of bits of wood and decayed plant stems. This was thought by Dr. Andrews to indicate a condition of low water between the Glenwood and Calumet stages; but it may with equal reason be regarded as a layer of lagoon muds and plant remains buried by the on-shore migration of the barrier. The crest of the ridge, where it is gravelly to the surface (and thus evidently an outer beach ridge unmodified by dunes) is usually about 38 feet above Lake Michigan. But locally the beach ridge is coated with wind-blown sand, which raises it several feet higher.

On the west side of the barrier are minor beach ridges and distinct hooks, which show that wave and current action in the Wilmette embayment was vigorous, and independent of the waves upon the lake. The best of these hooks diverges from the main ridge southwest of Rogers Park, running out a mile into the open bay, with a graceful curve, and ending near the center of section 25, just south of the Chicago city line (Plate VI). On it can be traced a gravelly beach ridge, built by the bay waves, and a higher dune ridge. Two small but very distinct branch hooks, with crests nearly as high as the Ridge avenue beach, occur in Rogers Park. A good place to see one of these is a field near the corner of Lunt avenue and Pine street. The low ground, protected by the long hook, is covered with fine lake sediments,—a stretch of true "lake plain," on which there are large truck farms. These hooked spits indicate clearly that there was pretty strong wave action in the Wilmette bay, inducing a northward shore current just opposite in direction to the shore current on the outer side of the Ridge avenue bar. The case is analogous to that of Sandy Hook and its branch spits (described on page 43); and a comparison of the two is

interesting and instructive. The dominant waves in the Wilmette bay came with a south or southwest wind, for they had the greatest "fetch." A short branch spit, which crosses Hill street just north of the Evanston golf links, at Ridge avenue, shows again the northward drift of beach material on the bay side of the great barrier.

Calumet Beach in the Waukegan District.—In the northern part of Waukegan, two miles north of the city (in section 9) scraps of terraces at altitudes appropriate to the Calumet stage appear on the face of the Toleston bluff; but some of these at least seem to be old ravine terraces, preserved in a curiously exposed position.

Near Beach Station (Fig. 32) the Calumet ridge appears on the brink of the Toleston bluff, and runs northward with short interruptions to the State line, never far from the bluff of the lower stage. Through Zion City it is followed by Elizabeth avenue. Near Winthrop Harbor it was cut away, during the Toleston stage, for half a mile. Although usually a low, faint feature, and subdued by plowing, it is broad and strong between Zion City and the Camp Logan road. Here a peaty deposit, lying between the Glenwood and the Calumet beach ridges, contains a great abundance of fresh water shells.*

Since these shells are all of living species and none have been found either here or elsewhere within the stratified deposits of the Calumet beach, they seem not to belong to Calumet time, but rather to the present. There are no certain traces of life in the lake during the Glenwood and Calumet stages.

INTERVAL BETWEEN THE CALUMET AND TOLESTON STAGES.

It is not known how far north the ice had receded during the Calumet stage before the Chicago outlet was lowered and Lake Chicago fell to 10 or 15 feet. There is reason to believe that soon after the fall occurred the ice uncovered a still lower outlet to the northeast and for a time the lakes experienced a low-water stage.

The chief evidences of this low-water stage are, (1) peat deposits buried by Toleston gravels in Evanston and elsewhere, and (2) drowned valleys on the east side of Lake Michigan, described by Leverett as a record of deep channeling in adjustment to a lake level at least 50 feet lower than the present, a channeling which took place after the Glenwood stage and before the Toleston.†

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* Identified by Mr. Bryant Walker of, Detroit: Lynnaea reflexa (Say.), Planorbis trivalvis (Say.), Planorbis bicannatis (Say.), Planorbis parvus (Say.), Physa elliptica (Lea.), Pisidium —?

† It is perhaps possible that these valleys were both deepened and drowned at a time subsequent to a 25-foot stage, for there is good evidence of a later low water stage.

LAKE ALGONQUIN, THE LOW-WATER STAGE, AND THE NIPISSING GREAT LAKES.

The name *Toleston* has been given to a group of shore lines in the Chicago district which lie from 10 to 25 feet above Lake Michigan. The Toleston beaches fall pretty definitely into two divisions, a higher group, from 20 to 25 feet above the lake, and a lower group, from 12 to 15 feet. The higher area always marked by beach ridges; the lower frequently by a distinct wave cut cliff.

Recent studies have strengthened the belief that the 15-foot member of the Toleston group of beaches does not mark the shore of a local Lake Chicago, but of two of its larger successors, Lake Algonquin and the Nipissing great lakes.*

While this is not yet fully demonstrated, it will be seen to explain certain features of the Toleston beaches in the Evanston-Waukegan district in a way which other interpretations fail to do, especially the strong development of the lower Toleston bluff.

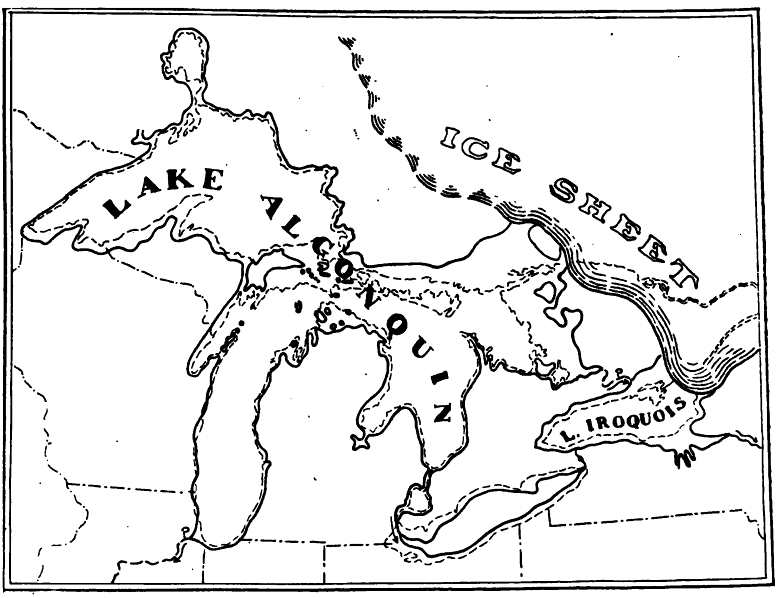

FIG. 34. Map showing the supposed outline of Lake Algonquin and its contemporaries. The position of the ice border is hypothetical. The outline of the lakes is known chiefly through the work of Taylor and Leverett.

Lake Algonquin occupied the whole of the Michigan and Huron basins and part or all of the Superior basin. It came into the Michigan basin when the ice had uncovered the Straits of Mackinac and Lake Chicago coalesced with its contemporary in the Huron

*See "Abandoned Shore Lines of Eastern Wisconsin," by J. W. Goldthwait. Wis. Geol. and Nat. Hist. Surv., Bull. XVII, 1907.

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Fig. A. Lower Toleston cliff and beach ridge.

Toleston beach ridge at Evanston.

basin. At that time the discharge of Lake Algonquin seems to have been eastward across Ontario, through the Trent valley, a region which at that time stood much lower than now; but it was later shifted to Port Huron, by uplifts of the more northerly region. The Chicago outlet may have shared to a slight decree in draining Lake Algonquin, but the outlet at Port Huron finally obtained the whole discharge by being cut down more rapidly than the outlet at Chicago. During the long Algonquin stage, the northern part of the great lake suffered tiltings or differential warpings, which brought the shores up out of water and left them in deformed attitudes, rising and diverging vertically toward the north. The Lake Michigan basin south of Manistee, however, and the Huron basin south of Point Au Barques seems to have been unaffected by the movements, so that the 15-foot beach in that southern portion of the Great Lake region is still horizontal.*

The Toleston Beaches—The main Toleston beach ridge makes its appearance not far north of the campus at Northwestern University, in Evanston. From the waterworks southward beyond the observatory, the inner half only of the beach ridge is preserved, on the brink of the present lake bluff. But at the north gate of the campus, the complete ridge runs inland from the lake, beneath Heck Hall and University Hall. (See Plate VII, Fig. B.) Thence its course through the city is on the east side of Chicago avenue to South Evanston, where it is followed pretty closely by Clark street to the southern borders of the map. (Plate VI.)

Its crest on the University campus is 24 feet above the lake, the upper 4 feet being sandy, though perhaps not from dune action. A recent cross-section in the bluff, where the ridge runs out to the lake, showed one foot of peat about 5 feet above the lake, beneath the Toleston gravels. Below the peat is a compact deposit of very fine gray sand, of unknown depth. A single shell was found in the sand close to the peaty layer. A section studied by Leverett in 1888 showed similar peat layers, with associated shell-bearing clays nine feet above the lake. Dr. Oliver Marcy, in 1864, made a record of an exceptionally good exposure in the cliffs, which were then unprotected by the piers and artificial beach. The peat, a clay bed containing molluskan shells of nine genera (all existing species) was found ten feet above the lake. Farther down, on the contorted glacial clays, was found a "humus soil, with stumps and logs (coniferous)," six inches thick and buried by three feet of gravel. A cellar excavation on Davis street, Evanston, recently showed a peat bed between the blue bowlder clay and the over-lying Toleston gravels and sands. Minute fibrous rootlets could be seen penetrating the till at the base of the peat, indicating that the deposit is *in*

* Leverett and Taylor have found no beach extending up to the region of coalescence, in either of the basins, above the Algonquin plane. In eastern Wisconsin, likewise, no beaches above the Algonquin seem to extend north of the Manistee moraine.

situ, presumably a land surface deposit. If so, it registers a stage of low water preceding the Toleston. A marl bed near the base of the Toleston gravels here, contains an abundance of shells.

South of Cavalry cemetery, through Rogers Park, the Toleston ridge is associated with a higher ridge of dunes, which lies between Clark street and the Northwestern railroad, and has an altitude of 25 to 30 feet above the lake. A measurement in a borrow pit near Calvary, where the gravel ridge is covered with five feet of sand, places the topmost gravel layer 22 feet above Lake Michigan. This seems, then, to be about the height of the outer Toleston beach.

Below this highest ridge of the Toleston group are always several lower beach ridges.*

In the Waukegan district no beaches occur at the 20 to 25-foot level. Beaches of this stage were destroyed by the recession of the bluffs when the lake stood about 15 feet above its present level (lower Toleston or Nipissing stage).

Lake Algonquin was extinguished by the recession of the ice front, uncovering a low pass between Lake Nipissing and the Mattawa river (east of North Bay, Ontario.) The waters fell considerably in adjustment to the new outlet and the Port Huron pass was left high and dry. It is not known just how far the lake fell to the new outlet. If the ten-fathom terrace already described on pages 48-50, is of significance in this connection, the drop as registered in the Michigan basin was about 60 feet. But this terrace is a questionable one. With a fall of 60 feet, the lake would have assumed some such outline as that shown in Figure 35.†

The low water stage was not to endure, however, for continued upwarping of the northern part of the lake region raised the North Bay pass up to, and at last above, the level of the recently abandoned Port Huron pass. Everywhere south of the rising outlet the lakes responded by rising on their shores until the waters overflowed again at Port Huron. (Fig. 36.) This transition stage, marking the climax of the rising of the lakes, when both the Nipissing and the Port Huron outlets were in use, has been called the stage of the Nipissing great lakes, and its shore line the Nipissing shore line. In the southern part of the Michigan and Huron basins the shore line of this stage seems to be 10 or 15 feet above the present lakes, and in a horizontal position; but toward the north the old shore line rises gradually and very uniformly as a result of the tilting. The shore lines of the Nipissing stage are characterized by an exceptionally strong development of cut bluffs and terraces, rather than by beach ridges. In this manner they express the vigorous encroachment of a lake which was rising upon its shores (see Fig. 29).

* On the University campus the Toleston ridges occur at heights of 24, 23, 19, 16 and 14 feet. At Chase avenue, Rogers Park, they are 30 feet (a dune covered ridge on the west side of Clark street), 23 feet (east side of Clark street), 23 feet, 16 feet (one block east of Clark street) and many others from 10 to 15 feet above the lake. There is reason for including those below 16 feet in the second or lower division of the Toleston.

† Recent studies strongly suggest that the low-water stage was very much lower than this—perhaps at about sea level.

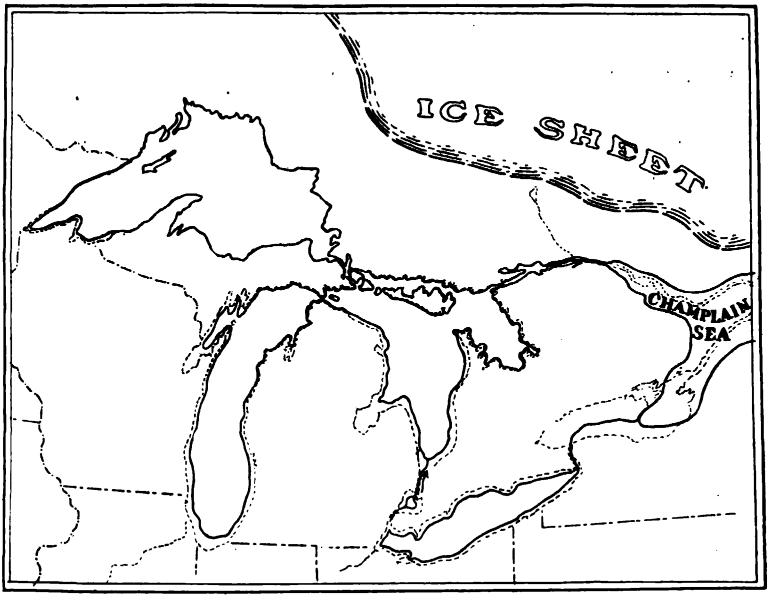

FIG. 35. Map showing a possible outline of the Great Lakes at the low water stage just preceding the Nipissing stage.

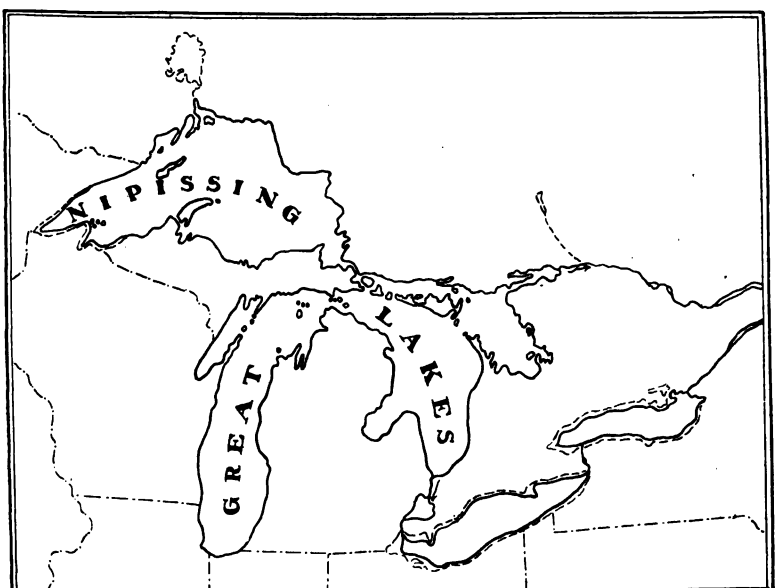

FIG. 36. Map of the Nipissing Grea Lakes. (After Taylor.)

At the close of the Nipissing stage, uplifts brought the North Bay outlet above water, and the discharge through the Saint Clair river was fully restored. From that time to the present, the only permanent changes in level have been a lowering of the lake, in response to the continued deepening and widening of the outlet. It is this lowering, without doubt, causing the lake to slowly withdraw from its Nipissing shore line, which resulted in the accumulation of the broad sand terrace of beach and dune ridges bordering the lake in the Waukegan district, and near Rogers Park.

Lower Toleston Bluff and Shore Terrace in the Waukegan District. —The rising of the waters from the low water stage to the Nipissing level was attended by vigorous cliff cutting in the Waukegan district. This is clearly shown by the conspicuous bluff which lies just west of the Chicago & Northwestern railroad all the way between Waukegan and the State line. (Plate VII, Fig. A.) In height, this bluff varies from 15 to 40 feet, according to the distance it receded into the upland. It is higher between Waukegan and Beach Station than north of that place. It is usually very steep except where long cultivation has favored the reduction of its steep slope. The base of the bluff, sometimes bordered by a cut and built terrace, is usually 13 or 14 feet above Lake Michigan; but near Waukegan it seems to be only 5 or 10 feet above the lake, probably because it was trimmed away during the subsequent fall of the waters to their present level. In general, however, the lowering of level has resulted in the over-shallowing of the shore, and the construction of a broad terrace of low sand ridges, described on page 52. Between Zion station and the lake, 24 of these sand ridges cross Shiloh boulevard. Farther south, the number becomes much less until near Waukegan there is only a broad marsh with sloughs between the Toleston bluff and the present beach. North of Zion the terrace becomes higher and drier and more extensively wooded.

EFFECTS OF RECENT FLUCTUATIONS IN LAKE LEVEL.

Since the settlement of the Great Lake region the level of Lake Michigan and Lake Huron has fluctuated noticeably. Not only is there a regular seasonal fluctuation of about one and one-half feet (high water coming in June or July, and low water in midwinter), but there are greater changes through periods of several years. In 1886 the lake was about two feet higher and in 1896 nearly three feet lower than in 1906. At high water in 1838 the lake stood nearly six feet higher than at low water in 1896. When these secular changes of level are plotted next to a rainfall curve* the connection between periods of unusual rainfall or drought and periods of high or low water is evident. With such considerable fluctuations, known by actual gauge measurements, it seems likely that a good part of the low coast near Waukegan has been built up within historic times.

* This has recently been done in "Geology of Huron County, Michigan," by A. C. Lane, Geol. Surv. of Mich., Vol. VII, Part 2, plate 5.

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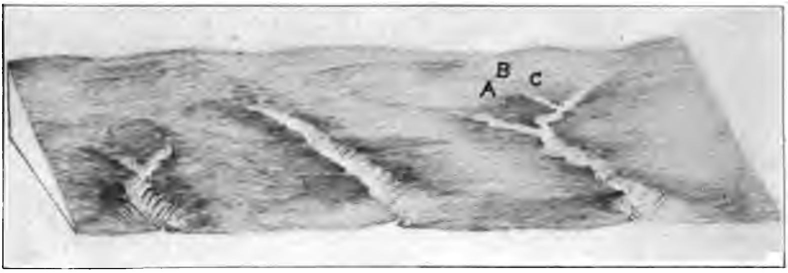

Fig. A. Moraine upland descending to lake shore.

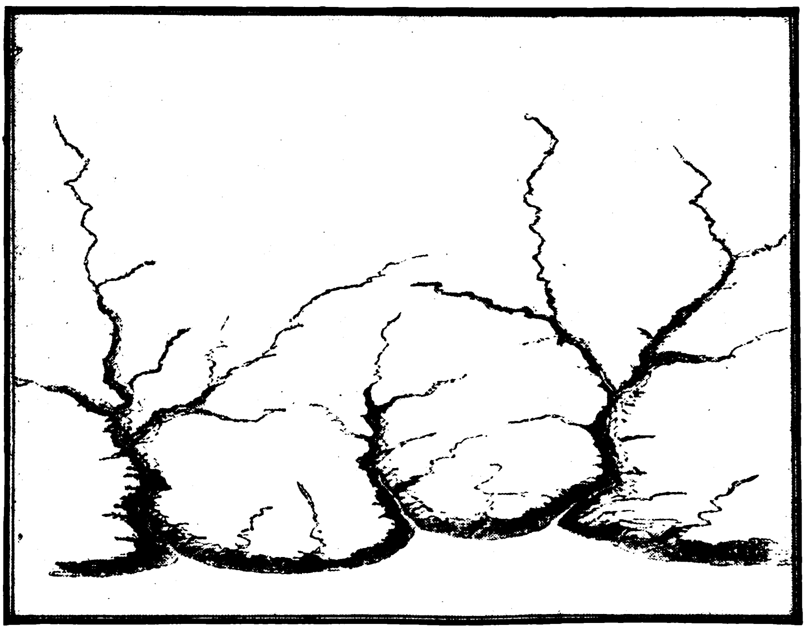

Fig. B. Young valleys. [Courtesy of Wisconsin Geol. Nat. Hist. Surv.]

THE DEVELOPMENT OF THE RAVINES.*

BY W. W. ATWOOD.

Morainic Surface—The surface of the drift, when exposed by the retreat of the ice, was probably somewhat rougher than much of the upland of today. The drift deposits bordering modern glaciers resemble the heaps of debris as they were left in this region. But the minor inequalities have been reduced in the process of soil making, or by the work of rain and running water. The larger features such as the hills or mounds and the larger depressions remain.

The broad open valley west of the lake ridge is not the result of erosion since the drift was deposited, but is a great depression left in the surface of the drift when the ice retreated. All of the ravines and valleys leading directly to the lake have been developed since the drift was deposited and are the result of rain water running off over the slope.

Origin of a Gully—When the ice melted, the upland extended farther to the east and presumably descended gradually to the level of the lake (Plate VIII, Fig. A.) As the rain fell upon this new land, a part of the water sank in, a part was evaporated, some collected in hollows or undrained depressions on the surface and the remainder ran off over the surface. The land, it is fair to assume, did not have an equal or uniform slope to the lake at all places, nor was the material over any considerable area perfectly homogeneous. The surface water tended to gather in the depressions of the surface, however slight they were. This tendency is shown on almost every hillside during and after any considerable shower. The water concentrated in the depressions is in excess of that flowing over other parts of the surface and therefore flows faster. Flowing faster, it erodes the surface over which it flows more rapidly, and as a result the initial depressions are deepened, and *washes* or *gullies* are started. (See Pl. VIII, Fig. A, and Pl. XI.)

Should the run-off not find irregularities of slope, it would, at the outset, fail of concentration; but should it find the material more easily eroded along certain lines than along others, the lines of easier wear would become the sites of greater erosion. This would lead to the development of gullies, that is to irregularities of slope. Either inequality of slope or material may therefore determine the location of a gully, and one of these conditions is indispensable.

* In the preparation of this portion of the text free use has been made of similar matter in Bull. V, Wisconsin Geol. and Nat. Hist. Surv., by Salisbury and Atwood.

Once started, each wash or gully becomes the cause of its own growth, for the gully developed by the water of one shower, determines greater concentration of water during the next. Greater concentration means faster flow, faster flow means more rapid wear, and this means corresponding enlargement of the depression through which the flow takes place. The enlargement effected by successive showers affects a gully in all dimensions. The water coming in at its head carries the head back into the land (head erosion), thus lengthening the gully; the water coming in at its sides wears back the lateral slopes, thus widening it; and the water flowing along its bottom deepens it. Thus gullies grow to be ravines and farther enlargement by the same processes converts ravines into valleys. A river valley therefore is often but a gully grown big.

The Course of a Valley.—In the lengthening of a gully or valley headward, the growth will be in the direction of greatest wear. Thus, in Plate VIII, Fig. A, if the water coming in at the head of the gully effects most wear in the direction A, the head of the gully will advance in that direction; if there be most wear in the direction B or C, the head will advance toward one of these points. The direction of greatest wear will be determined either by the slope of the surface, or by the nature of the surface material. The slope may lead to the concentration of the entering waters along one line, and the surface material may be less resistant in one direction than in another. If these factors favor the same direction of head-growth, the lengthening will be more rapid than if but one is favorable. If there be more rapid growth along two lines, as B and C, than between them, two gullies may develop. The frequent and tortuous windings common to ravines and valleys are therefore to be explained by the inequalities of slope or material which affected the surface while the valley was developing.

Tributary Valleys.—Following out this simple conception of valley growth, we have to inquire how a valley system (a main valley and its tributaries) is developed. The conditions which determine the location and development of gullies on a new land surface, determine the location and development of tributary gullies. In flowing over the side slopes of a gully or ravine, the water finds either slope or surface material failing of uniformity. Both conditions lead to the concentration of the water along certain lines, and concentration of flow on the slope of an erosion depression, be it valley or gully, leads to the development of a tributary depression. In its growth, the tributary repeats, in all essential respects, the history of its main. It is lengthened headward by water coming in at its upper end, is widened by side wash, and deepened by the downward cutting of the water which flows along its axis. The factors controlling its development are the same as those which controlled the valley to which it is tributary.

There is one peculiarity of the courses of tributaries which deserves mention. Tributaries, as a rule, join their mains with an acute angle up-stream. In general, new land surfaces, such as are now under consideration, slope toward the sea or some large body of water. If a tributary gully were to start back from its main at right angles, more

water would come in on the side away from the shore, on account of the seaward, or, as in the North Shore region, the lakeward slope of the land. This would be true of the head of the gully as well as of other portions, and the effect would be to turn the head more and more toward parallelism with the main valley. Local irregularities of surface may, and frequently do, interfere with these normal relations, so that the general course of a tributary is occasionally at right angles to its main. Still more rarely does the general course of a tributary make an acute angle with its main on the downstream side. Local irregularities of surface determine the windings of a tributary, so that their courses for longer or shorter distances may be in violation of the general rule. This case is well illustrated by the first tributary, from the lake, on the south side of Pettibone creek, near North Chicago (Fig. 48). This tributary leads toward the lake joining the main at an acute angle down stream. The encroachment by the waves has carried away the head of the gully and left a V-shaped notch in the cliff from which the drainage is inland.

On the whole, the valleys of a system, whose history has not been interrupted, in a region where the surface material is not notably heterogeneous, follow the course indicated above. This more general case is illustrated by nearly every drainage system along the shore from Winnetka to the Illinois-Wisconsin line.

How a Valley Gets a Stream.—Valleys may become somewhat deep and long and wide without possessing permanent streams, though from their inception they have *temporary* streams, the water for which is furnished by showers or melting snows. Yet sooner or later, valleys come to have permanent streams. How are they acquired? Does the valley find the stream or does the stream find the valley? For the answer to these questions, a brief digression will be helpful.

In cultivated regions, wells are of frequent occurrence. In a flat region of uniform structure, the depth at which well water may be obtained is essentially constant at all points. If holes (1 and 2, Fig.

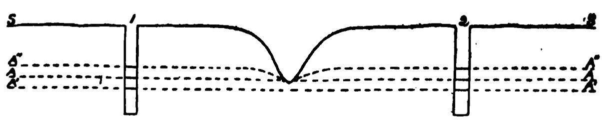

FIG. 37. Diagram illustrating the relations of ground water in streams.

37) be excavated below this level, water seeps into them, and in a series of wells the water stands at a nearly common level. This means that the sub-structure is full of water up to that level. These relations are illustrated by Fig. 37. The diagram represents a vertical section through a flat region from the surface (s. s.) down below the bottom of wells. The water stands at the same level in the two wells and the plane through them, at the surface of the water, is the *ground water level.* If in such a surface a valley were to be cut until its bottom was below the ground water level, the water would seep into it, as it does into the wells; and if the amount were sufficient, a permanent stream would be established. This is illustrated in Fig. 37. The line AA

represents the ground water level, and the level at which the water stands in the wells, under ordinary circumstances. The bottom of the valley is below the level of the ground water, and the water seeps into is from either side. Its tendency is to fill the valley to the level AA. But instead of accumulating in the open valley as it does in the enclosed wells, it flows away, and the ground water level on either hand is drawn down.

The level of the ground water fluctuates. It is depressed when the season is dry (A′ A′) and raised when precipitation is abundant (A″ A″). When it is raised, the water in the wells rises, and the stream in the valley is swollen. When it falls, the ground water surface is depressed, and the water in the wells becomes lower. If the water surface sinks below the bottom of the wells, the wells "go dry;" if below the bottom of the valley, the valley becomes, for the time being, a "dry run." When a well is below the lowest ground-water level its supply of water never fails, and when the valley is sufficiently below the same level, its stream does not cease to flow, even in periods of drought. On account of the free evaporation in the open valley, the valley depression must be somewhat below the level necessary for a well, in order that the flow may be constant.

It will be seen that ***intermittent*** streams, that is, streams which flow in wet seasons and fail in dry, are intermediate between streams which flow after showers only, and those which flow without interruption. In the figure the stream would become dry if the ground water level sank to A′ A′.

It is to be noted that a permanent stream does not normally precede its valley, but that the valley, developed through gully-hood and ravine-hood to valley-hood by means of the temporary streams supplied by the run-off of occasional showers, ***finds a stream,*** just as diggers of wells find water. The case is not altered if the stream be fed by springs, for the valley finds the spring, as truly as the well-digger finds a "vein" of water. Most of the North Shore gullies have but intermittent streams. A few are deep enough or have found a sufficient number of springs to have a permanent supply of water.

Limits of a Valley.—So soon as a valley acquires a permanent stream, its development goes on without the interruption to which it was subject while the stream was intermittent. The permanent stream, like the temporary one which preceded it, tends to deepen and widen its valley, and, under certain conditions, to lengthen it as well. The means by which these enlargements are affected are the same as before. There are limits, however, in length, depth and width, beyond which a valley may not go. No stream can cut much below the level of the water into which it flows, and it can cut to that level only at its outlet. Up stream from that point a gentle gradient will be established over which the water will flow without cutting. In this condition the stream is *at grade.* Its channel has reached *base level;* that is, the level to which the stream can wear its bed. This grade is, however, not necessarily permanent, for what was base level for a small stream in an early stage of its development is not necessarily base level for the larger stream which succeeds it at a later time.

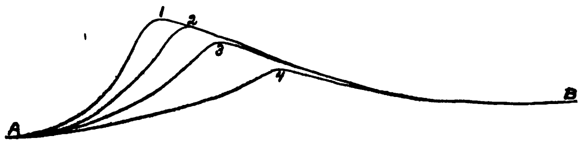

FIG. 38. Diagram showing the shifting of a divide. The slopes 1A and 1B are unequal. The steeper slope is worn more rapidly and the divide is shifted from 1 to 4, where the two slopes become equal and the migrating of the divide ceases.

Weathering, wash and lateral corrasion of the stream coninue to widen the valley after it has reached base level. The bluffs of valleys are thus forced to recede, and the valley is widened at the expense of the upland. Two valleys, widening on opposite sides of a divide, narrow the divide between them and may ultimately wear it out. When this is accomplished, the two valleys become one. The limit to which a valley may widen on either side is therefore its neighboring valley, and since, after two valleys have become one by the elimination of the ridge between them, there are still valleys on either hand, the final result of the widening of all valleys must be to reduce all the area which they drain to base level. As this process goes forward, the upper flat into which the valleys were cut is being restricted in area, while the lower flats developed by the streams in the valley bottoms are being enlarged. Thus the lower flats grow at the expense of the higher.

There are also limits in length which a valley may not exceed. The head of any valley may recede until some other valley is reached. The recession may not stop even there; for if, on opposite sides of a divide, erosion is unequal, as between 1A and 1B, Fig. 38, the divide will be moved toward the side of less rapid erosion, and it will cease to recede only when erosion on the two sides becomes equal (4A and 4B). In homogeneous material this will be when the slopes on the two sides are equal.

It should be noted that the lengthening of a valley headward is not normally the work of the permanent stream, for the permanent stream begins some distance below the head of the valley. At the head, therefore, erosion goes on as at the beginning, even after a permanent stream is acquired.

Under certain circumstances, the valley may be lengthened at its debouchure. If the detritus carried by it is deposited at its mouth, or if the sea bottom beyond that point rise, the land may be extended seaward, and over this extension the stream will find its way. Thus at their lower, as well as at their upper ends, both the stream and its valley may be lengthened.

A cycle of erosion.—If, along the borders of a new-born land area, a series of valleys were developed, essentialy parallel to one another, they would constitute depressions separated by elevations, representing the original surface not yet notably affected by erosion (see Plate VIII, Fig. B). These inter-valley areas might at first be wide or narrow, but in process of time they would necessarily become narrow, for once a valley is started, all the water which enters it from either side helps to wear back its slopes, and the wearing back of the slopes

means the widening of the valleys on the one hand and the narrowing of the inter-valley ridges on the other. Not only would the water running over the slopes of a valley wear back its walls, but many other processes conspire to the same end. The wetting and drying, the freezing and the thawing, the roots of plants and the boring of animals, all tend to loosen the material on the slopes or walls of the valleys, and gravity helps the loosened material to descend. Once in the valley bottom, the running water is likely to carry it off, landing it finally in the sea. Thus the growth of the valley is not the result of running water alone, though this is the most important single factor in the process.

Even if valleys developed no tributaries they would, in the course of time, widen to such an extent as to nearly obliterate the intervening ridges. The surface, however, would not easily be reduced to perfect flatness. For a long time at least there would remain something of slope from the central axis of the former inter-stream ridge toward the streams on either hand; but if the process of erosion went on for a sufficiently long period of time, the inter-stream ridge would be brought very low, and the result would be an essentially flat surface between the streams, much below the level of the old one.

The first valleys which started on the land surface (see Plate VIII, Fig. B) would be almost sure to develop numerous tributaries. Into tributary valleys water would flow from their sides and from their heads, and as a result they would widen and deepen and lengthen just as their mains had done before them. By lengthening headward they would work back from their mains some part, or even all the way across the divides separating the main valleys. By this process the tributaries cut the divides between the main streams into shorter cross ridges. With the development of tributary valleys there would be many lines of drainage instead of two, working at the area between two main streams. The result would be that the surface would be brought low much more rapidly, for it is clear that many valleys within the area between the main streams, widening at the same time, would diminish the aggregate area of the upland much more rapidly than two alone could do.

The same thing is made clear in another way. It will be seen (Plate IX, Figs. A and B) that the tributaries would presently dissect an area of uniform surface, tending to cut it into a series of short ridges or hills. In this way the amount of sloping surface is greatly increased, and as a result every shower would have much more effect in washing loose materials down to lower levels, whence the streams could carry them to the sea.

The successive stages in the process of lowering a surface are suggested by Fig. 39, which represents a series of cross sections of a land mass in process of degradation. The uppermost section represents a level surface crossed by young valleys. The next lower represents the same surface at a later stage, when the valleys have grown larger, while the third and succeeding sections represent still later stages in the process of degradation. Plate VIII, Fig. B, and Plate IX, Figs. A and B, represent in another way the successive stages of stream work in the general process of degradation.

Fig. A. The same valleys as shown in plate 8, fig. B, in a later stage of development.
[Courtesy of Wisconsin Geol. Nat. Hist. Surv.]

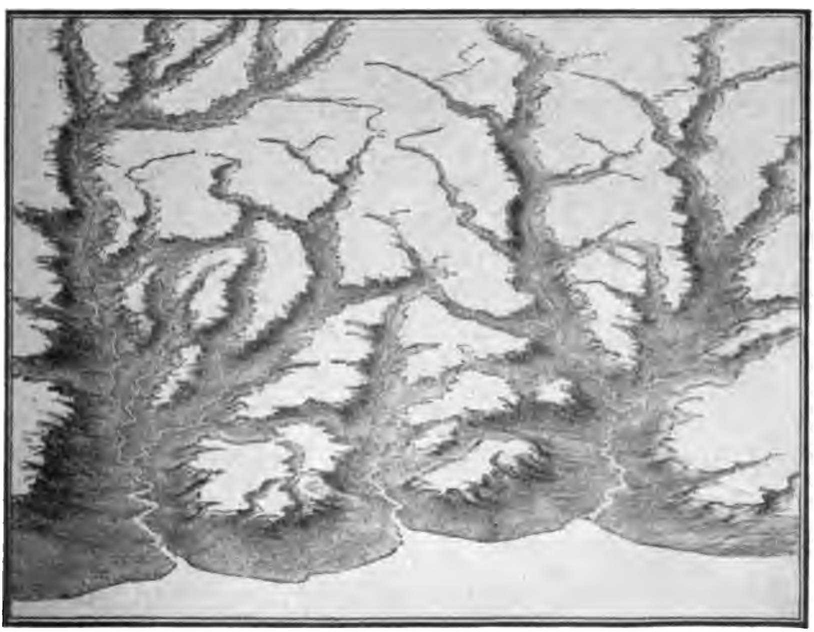

Fig. B. Same valleys as shown in fig. A in a still later stage of development.
[Courtesy of Wisconsin Geol. Nat. Hist. Surv.]

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In this manner a series of rivers, operating for a sufficiently long period of time, might reduce even a high land mass to a low level, scarcely above the sea. The new level would be developed soonest near the sea, and the areas farthest from it would be the last—other things being equal—to be brought low. The time necessary for the development of such a surface is known as a *cycle of erosion* and the resulting surface is a *base level plain;* that is, a plain as near sea level as river erosion can bring it. At a stage shortly preceding the base level sage the surface would be a *peneplain.* A peneplain, therefore, is a surface which has been brought toward, but not to base level. Land surfaces are often spoken of as young or old in their erosion history, according to the stage of advancement which has been made toward base leveling. Thus the Colorado canyon, deep and impressive as it is, is, in terms of erosion, a young valley, for the river has done but a small part of the work which must be done in order to bring its basin to base level.

Base level plains and peneplains.—It is important to notice that a plane surface (base level) developed by streams could only be developed at elevations but slightly above the sea; that is, at levels at which running water ceases to be an effective agent of erosion; for so long as a stream is actively deepening its valley its tendency is to roughen the area which it drains, not to make it smooth. The Colorado river, flowing through high land, makes a deep gorge. All the streams of the western plateaus have deep valleys, and the manifest result of their action is to roughen the surface. The ravines of the North Shore region have notably roughened the topography of that region. Given time enough, and the streams of any region will have cut their beds to low gradients. Then, though deepening of the valleys will cease, widening will not; and inch by inch, and shower by shower, the elevated lands between the valleys will be reduced in area, and ultimately the whole will be brought down nearly to the level of the stream beds. This is illustrated by Fig. 39.

It is important to notice further that if the original surface on which erosion began is level, there is no stage intermediate between the beginning and the end of an erosion cycle, when the surface is again level, or nearly so, though in the stage of a cycle next preceding the last—the peneplain stage (fourth profile, Fig. 39)—the surface approaches flatness. It is also important to notice that when streams have cut a land surface down to the level at which they cease to erode that surface will still possess some slight slope, and that to seaward. In the Evanston-Waukegan region the streams flowing into Lake Michigan can cut no lower than the level of the lake and the base level plain to which they are tending to reduce this region slopes gently lakeward.

No definite degree of slope can be fixed upon as marking a base level. The angle of slope which would practically stop erosion in a region of slight rainfall would be great enough to allow of erosion if the precipitation were greater. All that can be said, therefore, is that the angle of slope must be low. The Mississippi has a fall of less

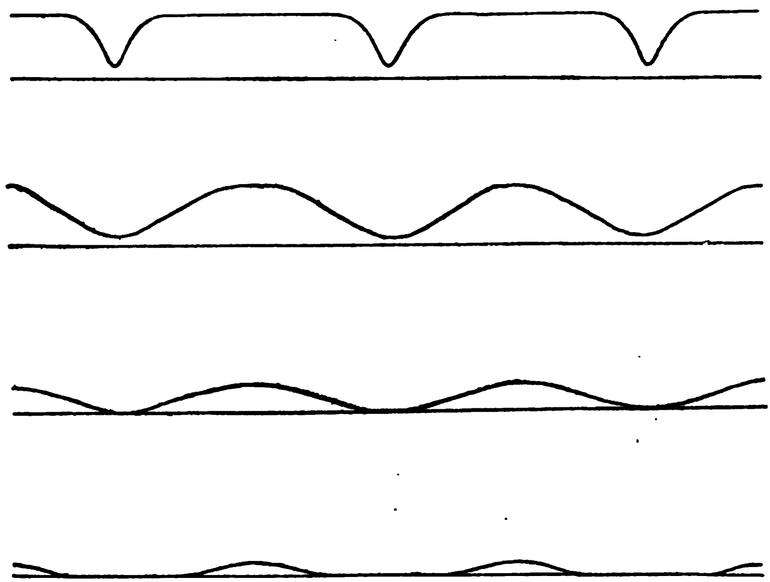

FIG. 39. Cross sections showing various stages of erosion in one cycle.

than a foot per mile for some hundreds of miles above the gulf. A small stream in a similar situation would have ceased to lower its channel before so low a gradient was reached.

Characteristics of Valleys at Various Stages of Development.—In the early stages of its development a depression made by erosion has steep lateral slopes, the exact character of which is determined by many considerations. Its normal cross section is usually described as V-shaped (Plate XI and Fig. 40). In the early stages of its development, especially if in unconsolidated material, the slopes are normally convex inward. If cut in solid rock, the cross section may be the same, though many variations are likely to appear, due especially to the structure of the rock and to inequalities of hardness. If a stream be swift enough to carry off not only all the detritus descending from its slopes, but to abrade its bed effectively besides, a steep sided gorge develops. If it becomes deep, it is a canyon. For the development of a canyon, the material of the walls must be such as is capable of standing at a high angle. A canyon always indicates that the down cutting of a stream keeps well ahead of the widening.

The profile of a valley at the stage of its development corresponding to the above section is represented diagrammatically by the curve A B in Fig. 41. The sketch (Pl. VIII, Fig. A) represents a bird's eye view of valleys in the same stage of development.

At a stage of development later than that represented by the V-shaped cross section the corresponding section is U-shaped, as shown in Fig. 42. The same form is shown in Plate X, Fig. A. This represents a stage of development where detritus descending the slopes is

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Fig. A. North fork of Pettibone creek, North Chicago.

Fig. B. A broad open valley north of Kenosha, Wis. [Courtesy of C. & N. W. Ry.]

not all carried away by the stream, and where the valley is being widened faster than it is deepened. Its slopes are therefore becoming gentler. The profile of the valley at this stage would be much the same as that in the preceding, except that the gradient in the lower portion would be lower.

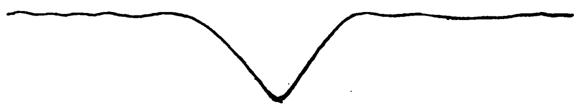

FIG. 40. Diagrammatic cross section of a young valley corresponding with the view shown in Plate XI.

FIG. 41. Diagrammatic profile of a young valley.

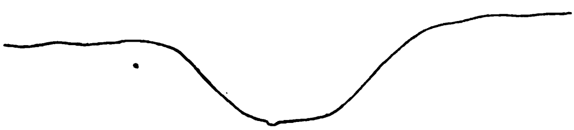

FIG. 42. Diagrammatic cross section of a valley at a stage corresponding with that shown in plate X, fig. A.

FIG. 43. Diagrammatic cross section of a valley at a stage later than that shown in fig. 42, and corresponding with the view shown in plate X. fig. B.

Still later the valley assumes the shape shown in Plate X, Fig. B, and the cross section shown in Fig. 43. This transformation is effected partly by erosion and partly by deposition in the valley. When a stream has cut its valley as low as conditions allow, it becomes sluggish. A sluggish stream is easily turned from side to side; and directed against its banks, it may undercut them, causing them to recede at the point of undercutting. In its meanderings it undercuts at various points at various times, and the aggregate result is the widening of the valley. By this process alone the stream would develop a flat at grade. At the same time all the drainage which comes in at the sides tends to carry the walls of the valley farther from its axis.

A sluggish stream is also generally a depositing stream. Its deposits tend to aggrade (build up) the flat which its meanderings develop. When a valley bottom is built up it becomes wider at the same time, for the valley is, as a rule, wider at any given level than at any lower

one. Thus the U-shaped valley is finally converted into a valley with a flat bottom, the flat being due in large part to erosion and in smaller part to deposition. Under exceptional circumstances the relative importance of these two factors may be reversed.

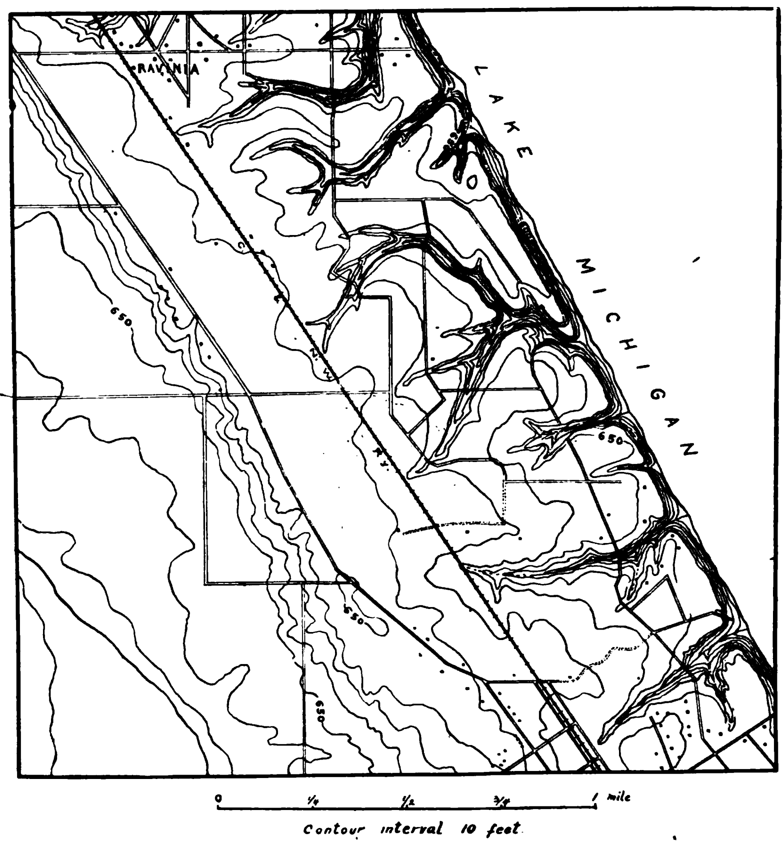

FIG. 44. Topographic map of a part of the North Shore near Ravinia, showing several young valleys.

It will be seen that the cross section of a valley affords a clue to its age. A valley without a flat is young, and increasing age is indicated by increasing width. Valleys illustrating many stages of development are to be found in the Evanston-Waukegan region. The gullies and ravines represent extreme youth (Fig. 44). An intermediate stage of development is shown in the valley of Pettibone creek (Plate X, Fig. A), North Chicago, and in the valley of Dead river west of Camp Logan. Old age is not illustrated in the region, for there has not been sufficient time since the ice melted for valleys to have reached that stage in a region where there is so much material to be removed.

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Plate XI. Erosive features near Fort Sheridan. Miniature erosive lines are shown in the glacial clay, and at the mouth of the main V shaped gully there is an alluvial fan. The fan has been dissected and a secondary fan is being developed on the beach. Waves have recently encroached upon the clay and developed a miniature lake cliff. [Courtesy C. & N. W.]

Transportation and Deposition.—Sediment is carried by streams in two ways: (1) By being rolled along the bottom, and (2) by being held in suspension. Dissolved mineral matter (which is not sediment) is also carried in the water. By means of that rolled along the bottom and carried in suspension, especially the former, the stream, as already stated, abrades its bed.

The transporting power of a stream of given size varies with its velocity. Increase in the declivity or the volume of a stream increases its velocity and therefore its transportive power. The transportation effected by a stream is influenced (1) by its transporting power and (2) by the size and amount of material available for carriage. Fine material is carried with a less expenditure of energy than an equal amount of coarse. With the same expenditure of energy, therefore, a stream can carry a greater amount of the former than of the latter.

Since the transportation effected by a stream is dependent on its gradient, its size and the size and amount of material available, it follows that when these conditions change so as to decrease the carrying power of the river, deposition will follow if the stream was previously fully loaded. In other words, a stream will deposit when it becomes overloaded.

Overloading may come about in the following ways: (1) By decrease in gradient, checking velocity and therefore carrying power; (2) by decrease in amount of water, which may result from evaporation, absorption, etc.; (3) by change in the shape of the channel, so that the friction of flow is increased, and therefore the force available for transportation lessened; (4) by lateral drainage bringing in more sediment than the main stream can carry; (5) by change in the character of the material to which the stream has access, for if it becomes finer, the coarse material previously carried will be dropped and the fine taken; and (6) by the checking of velocity when a stream flows into a body of standing water.

Topographic forms resulting from stream deposition.—The topographic forms resulting from stream deposition are various. At the bottoms of steep slopes, temporary streams build *alluvial fans.* These are commonly developed at the base of the lake cliff (Plate XI). Along its flood plain portion a stream deposits more or less sediment on its flats. The part played by deposition in building a river flat has already been alluded to. A depositing stream often wanders about in an apparently aimless way across its flood plain. At the bends in its course cutting is often taking place on the outside of a curve while deposition is going on in the inside. The valleys of Pettibone creek near North Chicago, and of Dead river near Camp Logan, illustrate this process of cutting and building in the flood plain.

Besides depositing on its flood plain, a stream often deposits in its channel. Any obstruction of a channel which checks the current of a loaded stream occasions deposition. In this way "bars" are formed. Once started the bar increases in size, for it becomes an obstacle to flow, and so the cause of its own growth. It may be built up nearly to the surface of the stream and in low water it may become an island by the depression of the surface water.

At their debouchures streams give up their loads of sediment. Under favorable conditions deltas are built. The material carried to the lake in the region under consideration is distributed along the shore by the waves and currents and therefore no deltas of notable size are developed.

Rejuvenation of Streams.—After the development of a base level plain its surface would suffer little change (except that effected by underground water) so long as it maintained its position. But if, after its development, a base level plain were elevated relative to sea level, the old surface in a new position would be subject to a new series of changes identical in kind with those which had gone before. The elevation would give the established streams greater fall and they would re-assume the characteristics of youth. The greater fall would accelerate their velocities, the increased velocities would entail increased erosion, increased erosion would result in the deepening of the valleys, and the deepening of the valleys would lead to the roughening of the surface. But in the course of time the *rejuvenated* streams would cut their valleys as low as the new altitude of the land permitted; that is, to a new base level. The process of deepening would then stop and the limit of vertical relief which the streams were capable of developing would be attained. But the valleys would not stop widening when they stopped deepening, and as they widened the intervening divides would become narrower and ultimately lower. In the course of time they would be destroyed, giving rise to a new level surface much below the old one, but developed in the same position which the old one occupied when it originated; that is, a position but little above sea level.

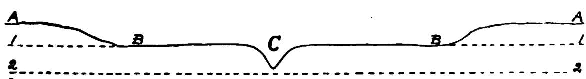

FIG. 45. Diagrammatic cross-section illustrating the topographic effect of rejuvenation by uplift. Compare with Fig. A, Plate XIII.

If at some intermediate stage in the development of a second base-level plain, say at a time when the streams had half completed their work, rejuvenation by uplift were to occur, the half completed cycle would be brought to an end and a new one begun. The streams would again be quickened, and as a result they would promptly cut new and deeper channels in the bottoms of the great valleys which had already been developed. The topography which would result is suggested by the above diagram (Fig. 45), which illustrates the cross section which would be found after the following sequence of events: (1) The development of a base level, A A; (2) uplift, rejuvenation of the streams and a new cycle of erosion half completed, the new base level being at B B; (3) a second uplift, bringing the second (incomplete) cycle of erosion to a close, and by rejuvenating the streams inaugurating the third cycle. As represented in the diagram, the third cycle has not progressed far, being represented only by the narrow valley, C. The base level is now 2-2, and the valley represented in the diagram has not yet reached it. (Compare with Fig. A, Plate XIII.)

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The rejuvenation of a stream shows itself in another way. The normal profile of a valley bottom in a non-mountainous region is a gentle curve, concave upward with gradient increasing from debouchure to source. Such a profile is shown in Fig. 46. Fig. 47, on the other hand, is the profile of a rejuvenated stream. The valley once had a profile

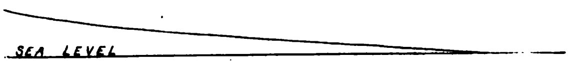

FIG. 46. Normal profile of a valley bottom in a non-mountainous region.

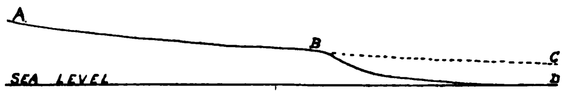

FIG. 47. Profile of a stream rejuvenated by uplift.

similar to that shown in Fig. 46. Below B its former continuation is marked by the dotted lines, B C. Since rejuvenation the stream has deepened the lower part of its valley and established there a profile in harmony with the new conditions. The upper end of the new curve has not yet reached beyond B.

The Influence of the Changes in the Level of Lake Michigan in Valley Development.—In this region certain of the older streams have been rejuvenated, not by an uplift of the land, but by the lowering of Lake Michigan. The lowering of the lake level depressed the base to which the streams could work, and therefore quickened the downward cutting in the valleys. All valleys that were developed before the subsidence of the lake waters must have been affected by this change. The narrow, V-shaped gullies continued to grow deeper, but did not essentially change in form. In valleys which had broad, flat bottoms at the time of the lowering of the lake, the deepening of the channel left the former bottom lands as terraces. These terraces grew smaller as the rejuvenated streams developed their new or inner valleys, and unless broad to begin with could not be expected to remain until today. In a few of the larger valleys such terraces have been identified. In Pettibone creek terrace remnants occur at several places in the valley (Fig. 48). The best preserved remnant is in the lower portion of the valley on the north side of the stream. This terrace is forty feet above the present lake level (C-T, Fig. 48). Following up stream, several remnants of the forty-foot terrace occur. They vary in width up to 300 feet and their surfaces retain the characteristic abandoned channels of old flood plains. This terrace corresponds in elevation to the Calumet stage of Lake Chicago.

Twenty feet above the stream, and about twenty-five feet above the present lake level, there are several distinct terrace remnants. These correspond with the Upper Toleston stage. In the area shown on Fig. 48 one such remnant (T-T) is brought out by the ten-foot contour map. Several other small remnants at the Upper Toleston level may

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outlet of the stream. The ponded waters rose, formed a considerable lake and overflowed. When the outlet of the valley lake was established, the waters of Lake Michigan were two to three feet higher on this side of the lake than when the picture was taken, for the outlet stream failed at that time to cut as low as at present. This is shown in the small terrace in the channel across the beach. The terrace corresponds to and is continuous with the miniature wave-cut terrace at the base of the small cliff in the sand and gravel on the beach. When the lake subsided from the sand and gravel cliff the stream was able to cut lower and entrenched its course to the depth shown in the view.

Each time that the level of Lake Michigan changed* the streams in the bordering lands were affected. When the lake level fell the streams were quickened and valley deepening was augmented (Fig. A, Plate XIII). When the lake level rose the lower portions of the valleys must have been drowned by the advancing lake waters. The streams lost velocity and began to fill or silt up their valleys. Examples of such filling are known in the larger valleys leading to Lake Michigan in Wisconsin. No good case is known in the Evanston-Waukegan area, but the valley of Dead river west of Camp Logan may have had such a history. There are at least eight feet of alluvium in the lower portion of the valley, just west of the station. Furthermore, the broad flat-bottomed form of the valley suggests that it has been partially filled with silts. The valley is larger than those developed by similar streams since the re-advance of the lake waters in Calumet times, and therefore would seem to have had a longer history. When the excavations are made at the mouth of Pettibone creek, in constructing a harbor for the United States naval training station, some interesting exposures are likely to be made.

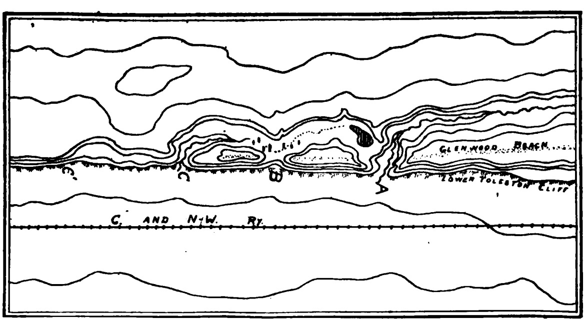

FIG. 49. Topographic sketch map of one of the head waters of Dead River between Waukegan and Beach. A, the present outlet; B, a possible former outlet; near C′ the original outlet.

One of the tributaries of Dead river between Waukegan and Beach has had a curious and interesting history. This valley trends southward on the west side of the Glenwood beach for some distance, and then turns sharply to the east, crossing the ancient shore lines and opening into the lake flat. The topographic sketch map (Fig. 49)

* The changes of lake-level are given in pp. 54-68.

shows the general form of the valley, the present outlet of the stream A, the ancient outlet near C′, and a possible former outlet at B. The location of the Glenwood and lower Toleston shore lines are also shown in the figure. Up stream from A the valley has a sharp inner gorge or trench cut below well marked Calumet and Toleston terraces. It is evident, therefore, that this portion of the valley was well developed during the Calumet stage of Lake Chicago; that when the lake waters fell to the Toleston level the valley bottom was appropriately lowered, and when the outlet at A was established the stream began cutting the inner trench.

Down the main valley from outlet A the higher Toleston level, about twenty-five feet above Lake Michigan, is well developed. It is evident that this valley bottom was reduced about as far as was possible during that time, and that a considerable flood plain was developed. In this portion of the valley there are also remnants of the lower Toleston flood plain. This means that the stream occupied this portion during a part at least of the lower Toleston time. Therefore, the diversion of the head waters through outlet A did not occur until late in Toleston time.

Between C and C′ there are terrace remnants that appear to be portions of old flood plains. This indicates that the valley extended southward from outlet C and that the east side of the valley has since been removed by wave cutting.

The sharp cliff shown in Fig. 49, west of the railroad, was developed by the waters of Lake Nipissing rising to the lower Toleston level. These waters cut away the east side of the valley between C and C′ and norrowed the morainic belt north of C and east of the valley. At A and B the valley swung to the east, and at these places the east wall became very narrow. Possibly the waves succeeded in cutting through to the valley at A and B somewhat as they are now doing at a point north of Kenosha, Wis.* There the flood plain is essentially at the level of the lake, but in the case shown in Fig. 49 the flood plain where the capture took place was about fifteen feet above the lake waters at that time. Possibly the actual capture of the stream was accomplished by a small stream working headward from the Nipissing cliff. When, by one or the other of these ways, the outlet A was established, the stream began entrenching its course above that point. If outlet B was ever occupied by much of a stream, it was not occupied by such a stream very long. The amount of cutting at that point is very slight. Since most of the waters are diverted at A, there is little outflow now at C.

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* Described in "Intercision, a peculiar kind of modification of drainage," by J. W. Goldthwait. School Sci. and Math., Vol. VIII, pp. 129-139, February, 1908.

Fig. A. Little Fort creek in the western portion of Waukegan. These terraces probably espond to the Calumet stage of Lake Chicago as shown in the valley development.

Fig. B. Glacial bowlders used in a building.

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UNDERGROUND WATER.

(BY W. W. ATWOOD.)

Shallow Ground Waters.—In what has preceded, reference has been made only to the results accomplished by the water which runs off over the surface. The water which sinks beneath it is, however, of no small importance in reducing a land surface. The enormous amount of mineral matter in solution in spring water bears witness to the efficiency of the ground water in dissolving rock, for since the water did not contain the mineral matter when it entered the soil, it must have acquired it below the surface. By this means alone, areas of more soluble rock are lowered below those of less solubility. Furthermore, the water is still active as a solvent agent after a surface has been reduced to so low a gradient that the run-off ceases to erode mechanically.

The seepage of ground water on steep valley slopes and on the lake cliff sometimes saturates the glacial clays and causes them to flow. These mud streams may often be seen near Fort Sheridan, Highwood and at other places where the cliff is not clothed with vegetation. At places the addition of ground water to the clay in a steep bank or bluff so increases the weight of the mass as to cause landslides. Such landslides are well known in the southeast portion of the Fort Sheridan grounds on the modern lake bluff. Sometimes the saturation of the clay in the lake and valley bluffs causes the clay to become so slippery that the overlying mass, which may be relatively dry, slides off and moves for some distance down the slope.

In the farming districts, within the Evanston-Waukegan area, ground water is reached in the common wells at depths varying from five to 100 feet. At some places the glacial drift contains very little water and the farmers have found it necessary to drill into the bed-rock formation to secure a good water supply.

Artesian Wells.—The village of Highland Park, the city of Waukegan, the Northwestern Railway and the Corn Products Refining Company at Waukegan, and numerous private citizens in the North Shore region, have artesian wells.

At Highland Park the public well is 1,590 feet deep. At L. E. Swift's, Lake Forest, the artesian well is 989 feet deep. At Mr. Booth's, Lake Forest, the artesian well is about 800 feet deep. At Miss Culver's, Lake Forest, there is an artesian well 2,062 feet deep. In South Evanston there is an artesian well 1,748 feet deep. (Fig. 50.)

There are two horizons from which the artesian water supply is obtained. One is reached at about 800 feet and continues downward for about 400. The lower horizon is reached between 1,300 and 1,500 feet and continues several hundred feet. The lower limit of this horizon has not been reached in the region.

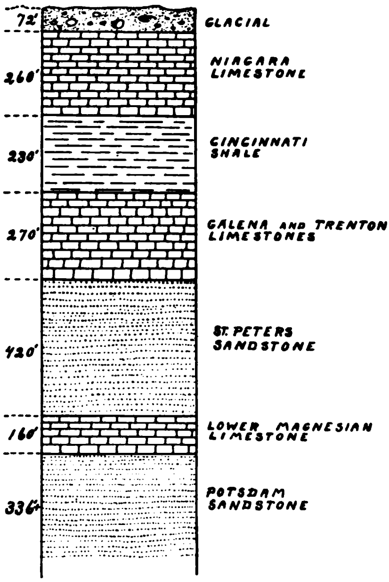

FIG. 50. Artesian well section in South Evanston showing the formations that underlie the entire Evanston-Waukegan region.

The waters in the artesian wells are supplied by the rainfall of central Wisconsin. The formations shown in Fig. 50 reach the surface in that region and descend gradually southward and southeastward under the Evanston-Waukegan area and much farther. The limestones overlying the St. Peters and Potsdam sandstones are relatively impervious, and the waters are retained in the porous sandstone layers until the overlying beds are punctured. The outcropping area of the St. Peters sandstone in Wisconsin is much less than that of the Potsdam (Fig. 51) and the thickness of the formation is also less. The lower water bearing horizon therefore contains a much larger supply than the upper.

Mr. Leverett has made the following report on wells within this region: "At Waukegan the public water supply was formerly obtained from artesian wells, but since 1895 it has been obtained by pumping from Lake Michigan. Three wells were sunk to depths of 1,135, 1,600 and 2,005, respectively. The first well is reported by Major DeWolf to have obtained water of fair quality, though rather heavily charged with iron. The second well obtained an unpleasant water with bad odor, thought to be sulphurous. The wells were discontinued because

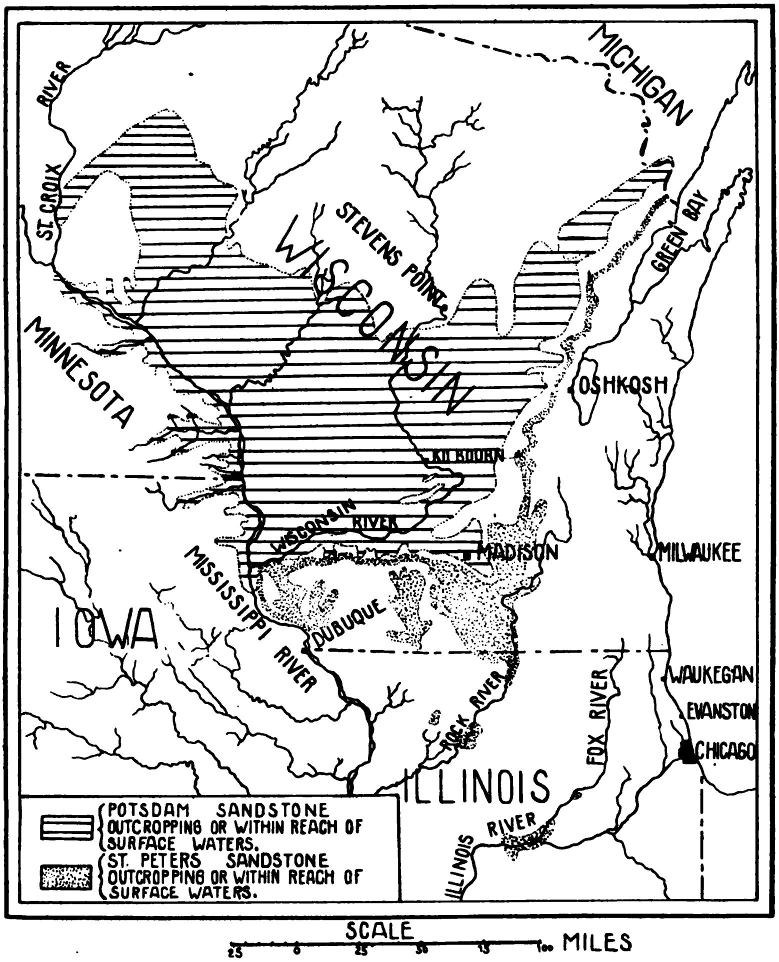

FIG. 51. Main absorbing areas for the Potsdam and St. Peters formations. From the 17th Ann. Rep. U. S. Geol. Surv., Part II. pl. CXI, by Frank Leverett.

of the hardness of the water, it being unfit for boiler use. The water also was found unsuitable for sprinkling lawns, it being destructive to grass. The Lake Michigan water is not too hard for boiler use and in other ways is more satisfactory than the artesian water. The present intake is at a distance of 1,700 feet from the shore, but it is proposed to extend the tunnel to a distance of about a mile.

"At Lake Forest, wells which yield thirty barrels per day are usually obtained at a depth of forty feet or less. An artesian well at the residence of Hon. C. P. Farwell reached a depth of 960 feet and obtained a flow of water whose head was originally fifty feet above the surface, or about 125 feet above Lake Michigan. The drift at this well has a thickness of 160 feet.

"At Highland Park there are four artesian wells with depths of 1,800 to 2,200 feet. Mr. P. T. Dooley, a well driller, residing at this village, reports that wells five inches in diameter yield about 150 gallons per minute. A strong flow of water is obtained at about 900 feet and also at about 1,300 feet, as well as at lower horizons. The wells all flowed when first made, but at present scarcely reach the surface. The elevation of the well mouths is 110 to 115 feet above Lake Michigan, or 690 to 695 feet above the sea. The thickness of drift is about 175 feet."

Tabulated Artesian Well Data.

(Compiled from Leverett's Report.*)

Locality and Owner.	Altitude.	Depth.	Capacity per minute.	Water bed and veins.
	Feet.	*Feet.*	*Gallons.*	
Evanston—city well	612	1,602	....	Limestone, 562-832 ft.
Highland Park—city well	685	2,200	150	Galena, 900 ft.; Lower Magnesian 1,300 ft.; Potsdam 1700-2200 ft.
Lake Forest—C. C. Farwell	650+	960	60	Probably St. Peters sandstone ....
Waukegan—old waterworks	600	1,135 1,600 2,005	....	St. Peters, Lwr. Magn. and probably Potsd.
Winnetka—Lloyd's well	658	1,570	150	Probably Lwr. Magn.

* Loc. cit., pp. 813-818.

Altitude of Top of St. Peters Sandstone in Chicago and Evanston-Waukegan Region.

(Compiled from Leverett's Report.*)

Location.	Altitude below tide.	Thickness
	Feet.	
Chicago	225+	200+
Evanston	222	420 ?
Highland Park	320	200
Lake Bluff	258	167
Winnetka	281	212

The surface of Lake Michigan is 581 feet above mean sea level.

* Loc. cit., p. 795.

GEOGRAPHIC CONDITIONS AND SETTLEMENT.

(BY W. W. ATWOOD.)

History.—When settlers came to northeastern Illinois in the early part of the last century, many of them selected the North Shore region in preference to the Chicago district. The old settlers who live in the district recall the days when Chicago was spoken of as a "mud hole." The site of Waukegan was selected for a city before that of Chicago, and a small village and fort were established east of Highwood near the shore, when Chicago was little more than a trading post. The region continues to be very attractive for suburban homes, and large industrial interests have been established at Waukegan.

Location of Roads.—Before the railroad was built north of Chicago there was a government highway from Fort Dearborn to Green Bay known as *the Green Bay road.* The location of this road was controlled by physiographic conditions. In the southern portion of the district, just north of Chicago, it was located on a beach ridge. This old shore line offered an even grade where the land was drier than on either side, and where the road material was sand and gravel. The road followed the ancient shore line through the present site of Evanston to the southern margin of Wilmette, where the beach ridge comes to the modern lake cliff. Ridge road, in Evanston, is a portion of the old Green Bay road. It is conspicuously above the general level of the lake plain and the homes now located there are favored by a good outlook and by good drainage through the beach material away from the basements and cellars.

Through Wilmette the government road was unfortunately near the lake cliff and was frequently washed away by the waves. At the foot of Lake avenue, Wilmette, as reported by C. P. Westerfield, a surveyor, at Waukegan, Ill., the present shore line is nearly 300 feet west of where it was in 1857. The original location of the old government road at this place is more than 200 feet east of the present shore line.

A short distance north of Winnetka the Green Bay road turned westward to avoid crossing the numerous ravines, and thence northward near the present line of the Chicago & Northwestern Railway. The old road turned westward just far enough to reach the uneroded rolling upland, and the modern steam and electric roads have taken advantage of the same route just west of most of the ravines. The railroads have built culverts where they cross the heads of some of the longer ravines.

The Grosse Point road, west of Evanston and Wilmette, is also an old highway, and was located on a beach ridge because of the peculiar

advantages offered by the sand and gravel. In the Chicago region there are several other illustrations of this same physiographic control of the early highways.

The roads or streets in the most recently surveyed village in the North Shore region show an interesting relationship to the topography of the village site. In the southern portion of Zion City there are several head-water ravines of one of the tributaries of Dead river, and the influence of these ravines on the location of the streets is clearly shown in Fig. 52. A similar topographic control of roads is illustrated in Lake Forest and to some extent in Highland Park.

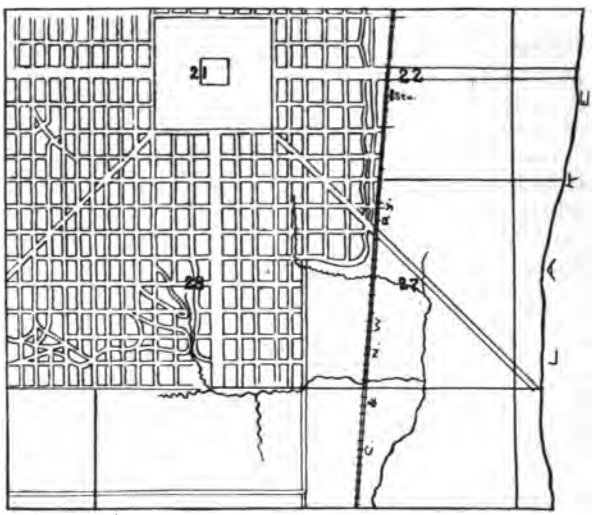

FIG. 52. Road map of the southern portion of Zion City.

Towns and Villages.—The margin of the lake flat where the rolling upland begins is a favorite site for villages. In the Chicago region beginning at the south, Dyer, Ind., Flossmoor, Chicago Heights, Homewood, Palos Springs, Palos Park, LaGrange, Galewood and Norwood Park are at this margin. In the Evanston-Waukegan region there are not many such sites, but Winnetka has such a location at the south, and Waukegan at the north. The opportunity for a harbor, the lake flat for wharfs and industrial plants, and the upland for the home district, were important factors that influenced the selection of the Waukegan site.

Soils and Sub-soils.—When the great ice sheet retreated the moraine deposits were exposed to the processes of weathering and erosion. The waters that went below the surface dissolved some of the mineral matter in the drift. Most of the calcareous material in the upper three to five feet of the drift has now been leached out. The clay in this upper zone usually fails to respond to acid as less exposed clay in the region will. Expansion and contraction due to changes in temperature loosened the material and made it more porous. The freezing and

Fig. A. Truck farm near Rogers Park.

Fig. B. Site of the town of St. John, showing two orchard trees that were in the western portion of the town. [Courtesy of C. & N. W. Ry.]

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thawing of the ground water also left the land less compact. For two or three decades after the retreat of the ice, judging from the present condition of the drift heaps along the Chicago Drainage Canal, this region was essentially barren. As plant life began to appear, the growth of roots assisted in loosening the ground, and the decay of vegetable matter contributed to the surface loam or soil. The decayed vegetable matter is dark brown or black, and today affects the color of the uppermost one or two feet in every exposure in the drift of this region. The oxidation of the iron-bearing elements in the drift has given to the five to ten feet underlying the soil a light yellow or buff color.

These various soil making processes are operative on the lake plain and on the upland, but they have affected the drift of the upland to slightly greater depths than that of the plain. Usually the uppermost zone of one or two feet, colored by decayed vegetable matter and much oxidized mineral matter, is defined as the soil. The somewhat oxidized, leached and loosened zone below the soil and above the unmodified drift is known as the sub-soil.

Unfortunately there is no exposure known in this region, that goes down to bed rock, showing the relation of the unmodified drift to the underlying rock formation. Judging from well data within the region and from exposures in the surrounding territory, we may, however, infer that if such exposure were made, the conditions would be as shown in Fig. 8. The drift would be sharply defined from the bed rock. The surface of the rock would undoubtedly show signs of glacial action such as striations, grooving and polishing. In regions not invaded by ice the relations are very different. In such regions the soil is derived directly from the disintegration of the rock at the surface and is known as residual soil. There is a gradual gradation from the soil into the sub-soil and downward through the less and less decomposed material to the unmodified bed rock, as shown in Fig. 13.

Most rock is more or less variable in composition and texture and therefore some parts yield more readily than others to the agents of weathering. The result is differential weathering, with the soil thicker at some places than at others. The sandy and gravelly soils found at some places in the southeast and northeast portions of the area are beach formations and were described in connection with the lake plain.

Farms.—In the southern portion of the region, the lowlands between the ancient beaches are largely used as truck farms. These areas were lagoons during certain stages in the retreat of the lake waters and from the abundance of decaying vegetable matter in such places came to have rich soils. The tendency of late has been to cover large portions of these lagoons with hot-houses (Plate XIV) and to raise vegetables for the Chicago and North Shore markets at all seasons of the year.

The rolling upland is excellent farm land. Over most of the moraine belt there is a loamy deposit several inches thick that is easily tilled and is very productive. Between Waukegan and Beach and extending

somewhat farther north there is a narrow four-foot bed of peaty material that is exceedingly rich soil and might be used for lawn or field dressing. The deposit is just west of the bluff which borders the railroad. Associated with the peat there is some bog iron ore but not in sufficient quantity to be of commercial value.

Suburban and Summer Homes.—The ravine country east of the railroad between Winnetka and North Chicago is largely devoted to suburban and summer homes. Its eastern margin borders the lake, and has lost much by the encroachment of the waves. In 1897 Mr. Leverett published the following statement.* "The rate at which the lake bluff is being encroached upon by wave action has become a matter of much concern to the residents. It is estimated by old settlers that from Waukegan to Evanston there has been, during the thirty years from 1860 to 1890, a strip about 150 feet in width, undermined and carried into the lake. This amounts to about 500 acres, representing at present valuation nearly one million dollars' worth of property."

The Former Village of St. Johns.—In 1845 and for about ten years following there was a village located in the southeast corner of what is now the Fort Sheridan grounds. This village was known as St. Johns. The chief industry was brick making, the yards employing as many as eighty men. A portion of the brick yard (Plates II, Fig. A, and XI) may now be seen and the boundaries of the kilns may be identified. In 1858 the railroad built a spur to the brick yards and the old railroad grade may be easily followed northeastward through the village of Highwood into the Fort Sheridan grounds. North of the clay pit remnants of a foundation and of an orchard are at the very margin of the lake cliff. Reports differ as to the amount of land that has been cut away at this point, but all agree that it was more than 100 feet. Some old settlers insist that 300 to 400 feet have been removed, and that the wearing away of the land caused the site to be abandoned. The orchard trees (Plate XIV, Fig. B) at the edge of the cliff and even overhanging are reported by some to have been in the yard to the west of the westermost house in the village. If this is true, the entire site of the village of St. Johns is east of the present shore line.

The Economic Uses of the Glacial Material.—The clay brought to this region by the glacier has been used in the manufacture of brick at several places. The manufacture of brick at St. Johns has been referred to. A few years ago brick was made at Spauldings, three miles west of Waukegan, and at North Chicago. The beach gravels are used in concrete work, for roofing and as road material. Large quantities of a fine grade of gravel, torpedo gravel, are used in concrete and at Waukegan in the manufacture of ready roofing material. The glacial bowlders are sometimes used very artistically in foundations or in chimneys, fences or gate posts (Plate XIII, Fig. B).

* Pleistocene features and deposits of the Chicago Area, Bull. II, Geol. and Nat. Hist. Sur. of the Chicago Academy of Sciences.

*Rainfall.**—Illinois is one of the most favored of the west-central states in the matter of rainfall. A deficiency of rainfall has never been so serious as to cause a complete failure of any crop over a great part of the State, such as the less humid states of the West and Northwest have experienced. Its greatest danger lies in a deficiency between June and September, there being many years when the corn and other crops which ripen in autumn are shortened by drought at that season. Often heavy rains and low temperature from April to June keep the ground cold and damp; then a reversal of conditions suddenly occurs and the ground becomes baked by the hot, dry atmosphere and blazing sun.

The average rainfall for Illinois is distributed as follows: Spring, 10.2 inches; summer, 11.2 inches; autumn, 9 inches; winter, 7.7 inches; giving an annual precipitation of 38.1 inches. The range in the rainfall at Chicago for the years 1867 to 1895, inclusive, was 23.4 inches, the lowest annual rainfall being 22.4 inches in 1867 and the highest 45.8 inches in 1883. In general, an annual precipitation of less than 25 inches results unfavorably to crops in Illinois, but this depends very largely upon its seasonal distribution. A year of 30 inches or more of rainfall at a given station may have a more prolonged and serious drought in the growing season, than one with but 24 inches.

* Quoted from Alden in the Chicago Folio, U. S. Geol. Survey. For additional information relative to the rainfall in Illinois see Mr. Leverett's paper on the "Water Resources of Illinois" in the 17th Ann. Rep. U. S. Geol. Surv. Part II. Also "The Illinois Glacial Lobe," Mongr. XXXVIII, U. S. Geol. Surv., Chapters XII, XIII, XIV.

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B.

Field Trips.

For the Study of Ravines and Valleys—

1. Dead river between Waukegan and Beach.
2. Little Fort river, Waukegan.
3. Pettibone creek, North Chicago.
4. Near Glencoe.
5. Near Ravinia.
6. Near County Line station on the Chicago & Milwaukee Electric railway.
7. At Beck's crossing, north of Glencoe.

For the Study of Shore Features—

1. Winnetka.
2. Ft. Sheridan.
3. South of Pettibone creek.

For Study of Old Beaches—

1. From Evanston Lighthouse west on Central street.
2. At Winnetka.
3. From Waukegan north to State line.

For Study of Dunes—

1. Rogers Park near Calvary cemetery.
2. North of Waukegan on lowland.
3. On beach between Lake Bluff and North Chicago.

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(102 pp. 48 fig. 14 pl.) State Geological Survey. Bulletin No. 7.

Goldthwait, James Walter, and Wallace W. Atwood

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